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ORIGINAL ARTICLES.

The Mountsorrel Granodiorite and Associated Igneous Rocks.

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(PLATE I.)

Introduction.

THE igneous rocks of the Mountsorrel area, by reason of their accessibility and economic value, have attracted the attention of geologists since the middle of last century. The latest and most comprehensive account of the district is that of E. E. Lowe (1)[1] and at the end of the paper a useful bibliography of earlier publications is given. Additional notes are to be found in the pamphlet published for the visit of the Geologists' Association to Charnwood Forest in 1928, including a structural study of the Mountsorrel "granite" by F. Jones (2).

Nevertheless, in certain respects, our knowledge of the complex has remained incomplete :—

(1) The accessory minerals of the rocks have, up to now, received no special study ;

(2) The petrogenetic processes involved in the formation and emplacement of the three main rock types of the complex have remained obscure.

In the present paper an attempt is made to deal with these two points.

I. The Accessory Minerals.

Method of Separation.

Specimens were collected from all parts of the complex and covering as wide a range of texture and composition as possible. The rocks were crushed in a hardened steel mortar, passed through a ½ mm. mesh sieve and separated in bromoform. Further division into non-magnetic and magnetic grades was effected by the electromagnet.

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[1] See list of references at end.

"*Index Figures.*"

For most of the samples the index figure or percentage of minerals with a higher specific gravity than 2·9 was determined. This figure gives a rough indication of the basicity of the rock and some 25 values have been plotted on the map of the complex in Fig. 1.

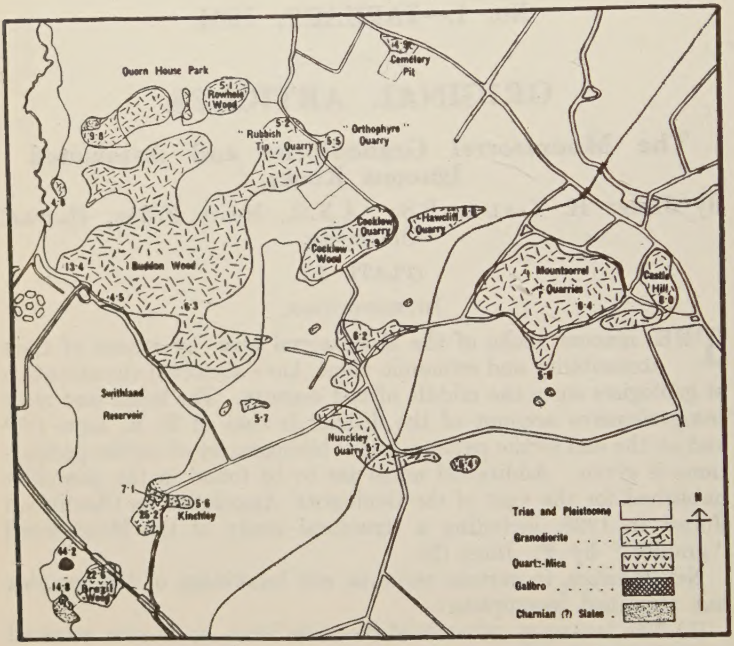

FIG. 1.—Map of Mountsorrel district (with index figures) Scale about 2 in. to 1 mile. Based on maps of H.M. Geological Survey.

At two localities (close to the Waterworks Dam and in the grounds of Quorn House) the granodiorite is clearly richer in coloured minerals than over the rest of its outcrop; and specimens from these two points yield the highest figures for the granodiorite (13·4 and 9·8). Lowe regards the two localities as being on the "basic fringe" of the granodiorite and postulates a gradual increase in basicity as one proceeds from the main Mountsorrel quarry westwards—the result of "differentiation in place". The index figures do not bear this out and it is certain that there is no regular increase in basicity, as both north and south of the basic granodiorite by the

Waterworks Dam there is acid granodiorite exposed. Actually the contact between the two rock types is visible, and they appear to represent separate intrusions though the nature of the contact suggests that they were injected more or less simultaneously.

Excluding the two basic portions the average index figure for the granodiorite is 5·8. The locality which gives the highest figure above the average is Cocklow Quarry, 7·2. Here there is no evidence, either in hand specimen or section, of basification, though xenoliths of the diorite occur just as in the main quarry and elsewhere. It appears evident that the diorite originally covered a greater area than it does to-day, for it is difficult to believe that the xenoliths in the main quarry travelled over a mile from the present outcrop of the diorite in an almost horizontal direction.

It is noticeable that wherever specimens of the red and white granodiorites from the same locality were examined, the white variety yielded an index figure slightly higher than the red. This is almost certainly due to the fact that the biotite of the white granodiorite is less chloritized than that of the red. The chlorite in question has a specific gravity very close to 2·9 and there is always a certain amount of it which does not come down in the bromoform. The corresponding biotite of the white granodiorite, however, is heavier than the bromoform and sinks readily. For this reason, the figures given in Fig. 1 had (for the sake of uniformity) all to be taken from specimens of the red granodiorite, since the white variety is restricted in its occurrence, and can only be obtained from certain of the larger and fresher excavations.

Description of Minerals.

A table of the mineral species present in samples from various localities is given on page 4. As in a former publication the minerals are listed under four headings :—

(1) Normal accessories.
(2) Pneumatolytic accessories.
(3) Contamination accessories.
(4) Secondary accessories.

Of these only classes 1, 2, and 4 are represented at Mountsorrel. While the normal accessories are very constant in their occurrence in the different samples, the pneumatolytic and secondary minerals, as one would expect, vary considerably from place to place.

Biotite.—In almost all the Mountsorrel rocks biotite occurs in sufficient quantity to place it among the essential minerals. The degree of chloritization varies considerably from place to place and, as Lowe has observed, the biotite of the white granite is usually somewhat fresher than that of the red. Pleochroic haloes surrounding zircon crystals in the biotite are abundant, but all efforts to obtain an average figure for their diameter failed, owing to the difficulty of determining the outer edge of the halo which is masked by the colour of the biotite.

			1. Normal Accessories										2. Pneumatolytic Accessories					4. Secondary Accessories							
		" Index Figure "	Biotite	Hornblende	Augite	Zircon	Apatite	Sphene	Pyrrhotite	Magnetite	Ilmenite	Orthite	Anatase	Rutile	Tourmaline	Topaz	Molybdenite	Chlorite	Epidote	Zoisite	Clino-zoisite	Pyrite	Limonite	White Mica	Calcite
Gabbro.	Swithland Reservoir . .	44·2	x	x	x	x	x	x	x	x	x		x	x				x		x	x			x	x
Diorite.	Brazil Wood	22·6	x	x		x	x	x	x	x			x					x	x		x				
,,	Dyke in hornfels, Brazil Wood	14·8	x	x		x	x		x	x								x	x				x		x
,,	Kinchley	25·2	x	x		x	x	x	x	x								x			x		x		
,, Xenolith.	Mélange, Kinchley . .	12·5	x	x		x	x	x	x	x								x	x					x	
Granodiorite.	West of Kinchley . . .	7·1	x	x		x	x	x	x	x								x	x	x					
,,	Mélange, Kinchley . .	5·6	x	x		x	x	x	x	x								x	x	x	x			x	
,, (basic)	Quorn House grounds . .	9·8	x	x		x	x		x	x				x				x					x		
,, ,,	Reservoir Dam . . .	13·4	x	x		x	x	x	x	x			x					x	x						
,, (acid)	,, ,, . . .	4·5	x	x		x	x	x	x	x								x	x						
,,	Rubbish Tip Quarry . .	5·2	x	x		x	x	x	x	x			x	x	x			x	x				x		
,,	Orthophyre Quarry . .	5·5	x	x		x	x		x	x				x				x							x
,, (red)	Cocklow Quarry . . .	7·9	x	x		x	x	x	x	x				x		x		x	x	x					x
,, (white)	,, ,, . . .	8·4	x	x		x	x	x	x	x			x	x				x	x	x	x			x	x
,,	South of Cocklow Wood .	6·2	x	x		x	x	x	x	x				x				x	x	x					
,,	Nunckley Quarry . . .	5·7	x	x		x	x	x	x	x			x	x				x	x						
,,	Cemetery Pit	4·9	x	x		x	x	x	x	x								x						x	
,, (red)	Main Mountsorrel Quarry .	6·4	x	x		x	x	x	x	x			x	x		x	x	x	x	x	x			x	x
,, (white)	,, ,, ,, .	8·7	x	x		x	x	x	x	x				x	x	x		x	x	x	x	x		x	x
,,	Castle Hill	6·0	x	x		x	x	x	x	x			x	x				x	x						
Granophyre.	Vein in mélange, Kinchley .	1·6	x	x		x	x	x	x	x		x		x				x	x		x				
Aplogranite Selvage,	Quorn House grounds .	2·2	x			x	x		x	x			x					x							
Aplite vein.	Main Mountsorrel Quarry .	0·9	x	x		x	x	x	x	x				x				x	x				x	x	x

Amphibole.—The dominant form in the gabbro is a brown variety with high extinction angle measured between C and Z of 23°, and absorption Z and Y dark brown, X pale straw: $Z = Y > X$. There are also smaller amounts of a dusky green variety, only slightly pleochroic, but apparently similar to the hornblende of the diorite (see below). In addition, there is a considerable amount of secondary amphibole after pyroxene,—uralite and pale green actinolite with a little colourless tremolite.

In the diorite green hornblende is extremely abundant and thin sections show that it occurs in large, irregular clotted masses. The maximum extinction angle measured was 16° and the pleochroism X very pale green, Y light brownish green, Z brownish green; $Z > Y > X$.

In the granodiorite hornblende is generally an accessory only, though in the "basic" granodiorite of the Reservoir Dam and Quorn House grounds it occurs in considerable quantity. The occurrence of pseudomorphs of chlorite after hornblende show that the latter was originally more abundant in certain portions of the "acid" granodiorite than it appears to be at present. The hornblende is a green variety with very slight pleochroism and the absorption appears to be $Z > Y > X$—the same as in the quartz-mica-diorite.

Pyroxene.—Augite is present only in the gabbro and is an almost colourless diopside. It shows good ophitic texture and zoning and has been locally replaced by secondary amphibole.

Zircon.—In most of the Mountsorrel rocks zircon is abundant, varied, and extremely interesting. Grouping of the crystals into classes is necessarily unsatisfactory, since there are about half a dozen factors—colour, size, crystal form, presence or absence of inclusions, zoning, etc.—all of which vary independently. Nevertheless, for purposes of description, central "types" must be distinguished.

(*a*) *Gabbro.*—From the gabbro two principal varieties of zircon are recognizable:—

(i) A small clear type with length/breadth ratio between 3 : 1 and 2 : 1, usually nearer the latter (Plate I, Fig. 1).[1] The average size is about 0·09 by 0·04 mm. Forms commonly present are (100), (101), (111), and (311): only in one or two cases was (331) recorded. A few of the crystals show corrosion round the edges.

(ii) Large irregular zircons showing little or no crystal form and often much fractured. Examples as large as 0·25 by 0·17 mm. were noted (Fig. 2).

(*b*) *Diorite.*—In the diorite the zircons show considerable variation from place to place, but three varieties are generally distinguishable:

(i) A small clear variety similar to (i) from the gabbro above, usually much corroded: one crystal showed well-developed zoning.

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[1] In this section subsequent references are all to figures on Plate 1.

(ii) Very irregular fragments similar to (ii) from the gabbro: these are never very abundant.

(iii) A large euhedral but rather unsymmetrical **variety is the** commonest of all (Fig. 4.) They are generally clear but sometimes a reddish staining appears; while globular inclusions and cavities are frequent. The average size of the crystals is about 0·20 by 0·09 mm. and the crystallography is usually very simple—often just (110) and (111). In the diorite of Kinchley crystals elongated along the C axis up to 0·42 by 0·09 mm. were noted (Fig. 5).

If, as suggested later, the diorite is of hybrid origin through assimilation of gabbro by acid magma, it is reasonable to suppose that types (i) and (ii) were largely derived as crystals from the gabbro while (iii) represents zircon which crystallized directly from the acid magma.

(*c*) *Granodiorite.*—The zircons from the granodiorite are extremely varied and an idea of the range in size and habit can best be obtained from Figs. 6 to 10 on Plate I. From most localities the zircons can be classified loosely under three divisions:—

(i) A short stout type with length/breadth ratio less than 2 : 1, some varieties being almost equidimensional.

(ii) A medium elongated variety—the dominant form—with length/breadth ratio between 2 : 1 and 3 : 1. Very variable in size from 0·11 by 0·04 mm. up to 0·33 by 0·12 mm.

(iii) A thin considerably elongated variety with length/breadth ratio up to 5 : 1.

Among the crystal forms commonly present were (110), (100), (111), (311), and (101)—the latter being the commonest of the bipyramids. The form (331) was very rare.

In most samples all varieties between clear and dusky zircons occur, while locally—as due south of Cocklow Wood—many of the crystals showed a red staining. Another very variable factor is the number of inclusions. At the Castle Hill, for example, inclusions are almost absent from many of the zircons, while in the granodiorite of Kinchley and the granophyre vein from the same locality the crystals are absolutely crowded with inclusions (Fig. 9). Zoning is quite frequently present, but is less perfect than that of the Dartmoor or even Jersey zircons.

From all parts of the granodiorite some of the zircons give evidence of corrosion. This is particularly marked in the zircons from the basic granodiorite of the Waterworks Dam and Quorn House grounds. At these points many of the crystals are almost completely rounded and show every sign of having been derived from some other rock.

An interesting, though not unexpected fact, is the extreme rarity of zircon in specimens from one of the aplite dykes representing the residual acid magma.

Apatite.—Next to zircon, apatite is probably the most interesting of the accessories.

(*a*) *Gabbro.*—Apatites from the gabbro seldom show good crystal form. Sections are either lath-shaped (usually without terminations) or quite irregular. The most interesting feature is the occurrence of dark coloured crystals. Some have just a dark core and clear borders, others a dark core and dusky borders, while some are uniformly dusky—almost black all over (Figs. 11 to 14). Occasionally slight pleochroism is shown and the direction of greatest absorption always corresponds with ϵ. Usually the high power of the microscope reveals that it is only the core that is pleochroic, but in the cases where the crystal is dusky all over with no visible core the whole crystal appears to be pleochroic. Similar dark apatites have been recorded from Triassic and other sediments in the Midlands (3), and from the granites of Leinster (4), Jersey (5), Galloway, the Ross of Mull (6), Eskdale, Cumberland (6*a*), etc.

(*b*) *Diorite.*—The apatites resemble those of the gabbro in being irregular, or at the best hemihedral in shape. Dark or cored crystals, however, are very much less common, though most of the apatites present are heavily charged with dark dust. These, however, are never pleochroic and are quite distinctive in appearance from the true dark variety.

(*c*) *Granodiorite.*—Apatite, though plentiful, is nothing like as abundant as in certain other granites (e.g. those of the Isle of Man). Irregular crystals are much commoner than euhedrons and where the latter occur they are of the simple forms shown in Figs. 1 and 2 of Dana (7), and the terminations are usually more or less rounded. The only crystal faces present are $(10\bar{1}0)$, $(10\bar{1}1)$, and (0001). The crystals are colourless but often with included dust particles: very occasionally cores of greenish chlorite are present. Only in one locality does the dark coloured variety occur—in the basic granodiorite from Quorn House grounds—where it is very abundant and often of an almost purple-blue coloration; colourless apatite is almost completely absent here. In the basic granodiorite of the Waterworks Dam, on the contrary, dark apatite is quite absent.

The distribution of the dark apatite is very difficult to explain. It is possible that its original source was the gabbro and that the examples in the diorite and basic granodiorite were derived from that rock by assimilation. An objection to this theory is that the dark apatites occur more abundantly in the basic granodiorite than in the gabbro itself. The only alternative suggestion seems to be that the formation of dark apatite required special conditions which only obtained locally at the time of consolidation of the rock.

Sphene.—Sphene is another widespread mineral, abundant in the granodiorite, less common in the diorite and gabbro. It occurs in large, irregular crystals up to about ·50 by ·45 mm. in size, ranging from almost colourless to deep brown, and showing strong dispersion. A yellow-brown moderately pleochroic type is perhaps the commonest; the colourless variety resembles zoisite but can be distinguished by its higher refractive index.

Although most of the sphene of the granodiorite appears to be primary small amounts of it are associated with biotite, occurring along the cleavages, and clearly of secondary origin.

Iron Ores.—Of the iron ores, magnetite and pyrrhotite are widespread ; the abundance of the latter in the Lake District granites was noted by Rastall and Wilcockson (8). Ilmenite was only definitely recorded from the gabbro. The identification of ilmenite in the presence of other iron ores is a matter of considerable difficulty. The method advocated by A. W. Groves, viz. testing chemically for titanium the material attracted by a large horseshoe magnet (5), appears unsatisfactory, since :—

(*a*) Ilmenite is not attracted by a horseshoe magnet (excepting varieties unusually rich in iron).

(*b*) Magnetite is frequently slightly titaniferous and responds to the test for titanium. Consequently, one has to rely on microscopic examination alone to reveal the presence of ilmenite.

Locally, in both diorite and granodiorite oxidation of magnetite has given rise to limonite. In the main quarry pyrite is locally common.

Orthite.—In the granophyre vein which cuts the mélange at Kinchley a few small fragments of a brown mineral, very pleochroic, light red-brown—dark brown, with extinction angle 30°, were referred to orthite.

Anatase.—Anatase is never common, but is widely distributed through gabbro, diorite, and granodiorite. It generally occurs in small, very irregular grains of a deep blue colour, showing strong dispersion. Where crystal form is recognizable, the sections are always basal, parallel to (001), sometimes modified by (111). The maximum size is about 0·12 mm. on edge.

Rutile.—Rutile is widespread in granodiorite and gabbro, but was not recorded from the diorite. Prismatic sections, with a combination of tetragonal prism and bipyramid are commonest but the faces are almost invariably rounded and do not show crystal form well. The average size is 0·15 by 0·05 mm. though much stouter crystals sometimes occur. The colour varies from honey-yellow to deep reddish brown. Genicular twins (on 101) were observed in both granodiorite and gabbro.

Tourmaline.—Tourmaline was only recorded from two localities —the granodiorite of the main quarry and of the " rubbish tip quarry ". The absorption scheme was ϵ very pale grey, ω dark grey brown.

Topaz.—Topaz is very scarce and small irregular fragments were recorded from only two localities—the main quarry and Cocklow Quarry.

Molybdenite.—Small amounts of silvery molybdenite were noted in the granodiorite of the main quarry.

Epidote Group.—The most abundant of these is common epidote, very widespread in the granodiorite but scarcer in the diorite. It is generally of a bright yellow-green colour and very conspicuous ;

locally, as at Cocklow Quarry, it becomes extremely abundant. In thin section it is seen to be intimately associated with the ferro-magnesian minerals.

Zoisite and clino-zoisite are always subordinate in amount to epidote but were recorded from nearly half of the specimens examined.

White Mica.—White mica occurs in both gabbro and granodiorite and is generally a paragonite secondary after plagioclose. In the aplite it is very abundant and appears to be a primary muscovite.

Calcite.—Calcite occurs in small quantities in gabbro, diorite, and granodiorite, and thin sections show that it is almost certainly secondary in origin.

II. The Genesis of the Rocks.

Origin of Diorite and Granodiorite.

Unfortunately direct evidence of the order of intrusion of the igneous rocks is lacking, save at Kinchley where granodiorite is seen to invade diorite. Lowe, however, gives reasons for believing the gabbro to be older than both (1) and with this the writer is in complete agreement. The variation of the magma was apparently along the normal basic → acid lines.

Chief interest centres round the origin of the diorite and the writer is strongly of the opinion that it is a hybrid formed by action of acid magma on basic rock, rather than a straightforward differentiate from a gabbro magma. Harker's dictum that " in no case can the hybrid origin of a rock be concealed " (9) cannot be accepted to-day, and it is difficult to devise criteria whereby hybrids may be recognized. A common feature of these rocks is extreme variability from place to place. In the case of the Mountsorrel diorite this is brought out by the index figures which are : dyke in hornfels S.W. of Reservoir Shore 14·8, Brazil Wood 22·6, and Kinchley 25·2. A cursory examination of thin sections from the three localities corroborates the evidence of the index figures with regard to ferro-magnesian constituents and it might be expected that the amount of quartz would vary in inverse relation to the coloured minerals. Micrometric analyses, however, gave the following results : dyke in hornfels S.W. of Reservoir Shore 23·8 per cent quartz, Brazil Wood 9·0 per cent, and Kinchley 14·8 per cent. From these figures it will be seen that, according to Shand's classification, the rocks from the dyke on Reservoir Shore and Kinchley fall right outside the intermediate class, and " diorite " is strictly speaking a misnomer.

Under the microscope the rocks from the three localities show very considerable variation. The dyke from the Reservoir Shore contains abundant biotite while hornblende is almost absent. Though in the hand specimen it resembles the diorite of Brazil Wood, under the microscope it seems more closely allied to the granodiorite.

The " diorite " of Kinchley contains abundant hornblende as well as biotite and on account of the high percentage of quartz present closely resembles the basic granodiorite of Quorn House grounds and the Reservoir Dam. The Brazil Wood rock is the typical quartz-mica-diorite described by Lowe. All three show the strewing about of the coloured minerals that Bowen regards as a result of assimilation (10) and that is a characteristic feature of the hybrid rocks of Jersey (11), Sark (12), Christiania (13), the Isle of Man (14), etc. The corroded nature of many of the zircons from the diorite has already been mentioned (page 5).

The " solid " parent of the diorite was without doubt the gabbro. The nature of the " liquid " parent must necessarily be less certain, but fortunately we can form some idea as to its composition. In Quorn House grounds, where the basic granodiorite is seen cutting the shales, there is along the contact a thin selvage some 6 inches thick of a very distinctive character. Its acidity is evident from the index figure of only 2·2, and in thin section it is seen to be a fine-grained aplogranite, consisting of quartz, two varieties of felspar, and a little chloritized biotite. The dominant felspar is a plagioclase with a wide extinction angle and refractive index well below balsam, indicating that it is close to the albite end of the series. A little orthoclase is also present but its refractive index is so near to that of the albite that it is difficult to estimate its proportions. Somewhat similar rocks, described as thin dykes cutting the hornfels of Brazil Wood, were exposed in the course of excavations at the time the Swithland Reservoir was constructed (15).

There can be little doubt that the selvage represents the first acid magma to be intruded in the area " frozen in " by contact with the cold shale and it is not entirely surprising to find that it is of soda-aplogranite type. The inference is that the granodiorite did not crystallize from a magma of its own composition, but must be due to basification of this initial aplogranite magma : for it is impossible to conceive of normal differentiation by crystal sorting operating along the lines gabbro → aplogranite → granodiorite. The material added to the initial acid magma must have been either gabbro or diorite, most probably both. The abundant igneous inclusions in the granodiorite have generally the composition of acid quartz-mica-diorite, but whether this indicates that they were originally diorite, or gabbro that has attained its present composition by reaction with the acid magma, is doubtful. One may regard the diorite, basic granodiorite, and granodiorite as forming a series due to basification of the original aplogranite magma —the increase in acidity being due to :—

(1) Continuous uprise of fresh supplies of acid magma ;

(2) The later members of the series being formed to a less extent by reaction of magma with gabbro, and to a greater extent by reaction with the earlier formed hybrids (e.g. diorite and basic granodiorite).

The intermixture of acid magma with basic and intermediate rock may have taken place either (*a*) in situ, or (*b*) below the present ground surface, with subsequent re-injection of the basified magma at a higher level.

That the latter is the correct explanation in the case of the granodiorite is shown by the sharp, straight contact between acid and basic granodiorite close to the Waterworks Dam.

The formation of intermediate rocks by intermixture of acid magma with basic rock is a process familiar to petrologists and several instances of similar occurrences have already been mentioned (page 10). The writer has elsewhere (16) expressed his opinion that the monzonitic and tonalitic suites are more commonly formed in this way than in any other. Examples of granodiorites with a similar hybrid origin are much less frequent, but the history of the Dhoon granodiorite, Isle of Man (14), is very similar to that of Mountsorrel. It is regarded by Nockolds as the result of contamination of alkali-granite magma by incorporation of basic rock similar in composition to the greenstone dykes of the neighbourhood.

CHEMICAL ANALYSES.

Three new chemical analyses have kindly been prepared by Mr. W. H. Herdsman and are given in the accompanying table, together with similar analyses for comparison.

	I	I*a*	I*b*	II	II*a*	II*b*	III	III*a*
SiO_2	46·10	48·11	47·5	60·90	59·47	58·31	76·70	73·52
Al_2O_3	19·95	17·86	15·6	15·55	16·52	16·97	12·58	12·86
Fe_2O_3	1·00	0·43	2·6	0·96	2·63	1·45	0·10	1·48
FeO	6·04	5·20	7·1	5·25	4·11	4·42	2·09	1·54
MgO	10·70	9·53	11·7	4·45	3·75	4·09	0·65	0·57
CaO	10·10	12·42	9·8	5·20	6·24	5·66	1·10	2·08
Na_2O	1·30	2·34	1·4	2·45	2·98	3·80	4·90	4·36
K_2O	0·45	0·64	1·5	2·03	1·93	2·51	0·52	1·41
H_2O − 105° C.	0·40	0·14	2·4	0·25	1·39	0·70	0·35	0·35
H_2O + 105° C.	2·60	0·84		1·55		0·79	0·50	1·21
TiO_2	0·90	0·75	—	1·05	0·64	0·87	0·20	0·51
MnO	0·25	0·30	—	0·20	0·08	0·05	0·12	0·08
P_2O_5	Trace	0·07	—	Trace	0·26	0·51	0·02	0·07
CO_2	*Nil*	0·54	—	*Nil*	—	—	*Nil*	*Nil*
S	Trace	—	—	Trace	—	—	*Nil*	*Nil*
	99·79	100·14	99·7	99·84	100·00	100·14	99·83	100·04

I. Gabbro, Swithland Reservoir, nr. Mountsorrel, analyst W. H. Herdsman.

I*a*. Olivine-gabbro, Huntly mass, Aberdeenshire; analyst E. G. Radley.

I*b*. Biotite-diorite, West of Ben Damhain, Garabal Hill; analyst Player.

II. Quartz-mica-diorite, Brazil Wood, nr. Mountsorrel; analyst W. H. Herdsman.

II*a*. Average of 20 quartz-diorites, Daly.

II*b*. Quartz-augite-hypersthene-porphyry, Dundee Law; analyst F. Walker.

III. Soda-aplogranite selvage, South of Quorn House, nr. Mountsorrel; analyst W. H. Herdsman.

III*a*. Oligoclase-granite, Preston, Connecticut; analyst George Steiger.

The Mountsorrel gabbro as compared with the Huntly olivine-gabbro and the Garabal Hill biotite-diorite is high in alumina and slightly low in alkalies; in most other constituents it is intermediate between the two. The quartz-mica-diorite is close to Daly's average of 20 quartz-diorites; but as compared with the quartz-augite-hypersthene-porphyry of Dundee Law it is high in silica and low in alumina and alkalies. The most striking feature about the aplo-granite selvage is the very low potash and relatively high soda. It compares reasonably closely with the oligoclase-granite of Preston, Connecticut, but the latter is richer in potash, lime, and ferric iron.

The norms corresponding to the three new analyses together with that for the Mountsorrel granodiorite have been calculated in the usual manner and are set out below :—

	A	B	C	D
quartz	—	17·52	27·78	42·90
orthoclase . . .	2·78	12·23	18·91	3·34
albite	11·00	20·95	33·01	41·39
anorthite . . .	47·25	25·01	9·73	5·56
plagioclase composition .	$Ab_{19}An_{81}$	$Ab_{46}An_{54}$	$Ab_{64}An_{36}$	$Ab_{88}An_{12}$
olivine (forsterite) .	7·98	—	—	—
,, (fayalite) . .	4·08	—	—	—
hypersthene ($MgSiO_3$) .	14·60	10·90	3·60	1·60
,, ($FeSiO_3$) .	4·20	7·39	1·72	2·05
diopside ($CaSiO_3$) . .	1·16	0·35	—	—
,, ($MgSiO_3$) . .	0·80	0·20	—	—
,, ($FeSiO_3$) .	0·26	0·13	—	—
corundum . . .	—	—	1·63	1·84
ilmenite . . .	1·67	1·98	0·91	0·45
magnetite . . .	1·39	1·39	1·86	0·23
calcite . . .	—	—	1·00	—
apatite . . .	—	—	0·34	—

A. Gabbro. C.I.P.W. Classification, Class II, Order 5, Rang 3, Subrang 4—Andose.

B. Quartz-mica-diorite. Class II, Order 4, Rang 3, Subrang 4—Tonalose.

C. Granodiorite. Class I, Order 4, Rang 2, Subrang 4—Lassenose.

D. Soda-aplogranite. Class I, Order 3, Rang 2, Subrang 5—Yukonose.

The most interesting feature of the analyses is the proportions of alkalis in the granite selvage. In all the rocks of the Mountsorrel suite soda is dominant over potash, but in the selvage this dominance is extreme and the ratio $Na_2O : K_2O$ reaches 8·3. This is due entirely to fall in potash as the variation diagram (Fig. 2) shows a practically linear curve for soda. If this be taken to indicate that the initial acid magma at Mountsorrel was of a strongly sodic nature the case is a parallel one to that of the Dartmoor granite where Brammall (17) reaches a similar conclusion from an examination of the felsites and "chilled margins" of the mass. Nevertheless, even in the felsites of Dartmoor the $Na_2O : K_2O$ ratio does not rise higher than 2·2.

It is probable, however, that the sodic character of the initial acid magma at Mountsorrel is over-emphasized by the selvage. Bowen (10) has inferred from the absence of glasses corresponding in composition to the soda granites that magmas (liquids) of such composition do not exist and an almost exactly similar conclusion has been reached by Lacroix (18). If this be the case, the selvage at Mountsorrel will not represent the initial acid magma but a differentiate from it; but as the selvage was probably "frozen in" before this differentiation could proceed very far we may regard it as not greatly removed from a true magma type.

If the formation of hybrid rock types consisted solely in the mixing of two end terms, one would expect the variation diagram of such a series to be a straight line one. Harker, however, dismisses this idea (19): "The processes which have operated in the case of the Kilchrist and Marsco rocks were of a less simple kind, mere admixture being supplemented by diffusion. The resulting hybrid rocks in such a case are thus only in a general sense intermediate in composition between the two parent rocks. . . . In other words series consisting of two extreme rock-types and the various hybrid rocks which they have generated will not in general be a "linear" series as regards chemical composition."

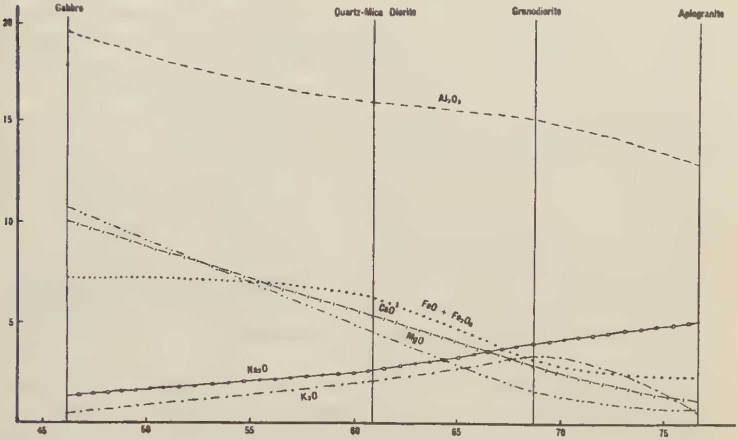

FIG. 2.—Variation diagram of the igneous rocks of the Mountsorrel district.

In the case of the Mountsorrel rocks the composition of the following admixtures has been calculated:—

(1) One part gabbro to one part soda-aplogranite.
(2) One part gabbro to three parts soda-aplogranite.
(3) One part quartz-mica-diorite to one part soda-aplogranite.

	(1)	(2)	(3)
SiO_2 . .	61·40	69·05	68·80
Al_2O_3 . .	16·26	14·42	14·07
Fe_2O_3 .	0·55	1·82	0·53
FeO . .	4·07	3·08	3·67
MgO . .	5·67	3·16	2·55

	(1)	(2)	(3)
CaO	5·60	3·35	3·15
Na_2O	3·10	4·00	3·68
K_2O	0·49	0·50	1·28
H_2O	1·92	1·36	1·32
TiO_2	0·60	0·38	0·63
MnO	0·18	0·15	0·16

It will be seen that (1) corresponds approximately to the quartz-mica-diorite, and (2) and (3) to the granodiorite; in general they show very low potash and rather high magnesia, lime, and ferrous iron compared with the actual analyses. The main problem is how to account for the considerable discrepancy in potash content and here again the case seems analogous with that of Dartmoor. Brammall has proved beyond any reasonable doubt that the initially sodic Dartmoor magma was enriched in potash by assimilation of the shales into which it is intruded. It is at least worthy of consideration that a similar state of affairs obtained at Mountsorrel, for inclusions of the slaty country rock occur in both granodiorite and quartz-mica-diorite. It is impossible to say to what extent the slates have been incorporated in the magma, for they would be readily transformed into phases with which the magma was saturated and would lose their identity. It is only where the process was checked that inclusions of the slates remain as such. Analysis of the Brazil Wood hornfels (20) shows a K_2O percentage of 3·66 as against 1·00 Na_2O, which appears adequate to account for the amount in diorite and granodiorite. Where the slaty fragments were not completely assimilated reciprocal reaction between them and the surrounding magma may in part account for the deficit in magnesia, lime, and ferrous iron of the true over-calculated analyses of the granodiorite and diorite. Thomas (21) records that the xenoliths of the tholeiite dykes of Mull are enriched in these three constituents. The exact nature of the processes at Mountsorrel, however, can only be made clear when many more chemical analyses are available.

The origin of the initial acid Mountsorrel magma is not a matter that can be definitely determined. That it could have resulted as a differentiate from a primary basic magma having a composition similar to the gabbro of the Swithland Reservoir is beyond doubt. Similar derivation of sodic granites from normal gabbros has been demonstrated in the case of the Glen More ring dyke in Mull (22), and the Preston gabbro of Connecticut (23). That such a process was aided by the palingenesis of earlier granitic rocks is more in line with the views of Daly (24), Holmes (25), and Brammall (17). In either case there could have originated phases intermediate in composition between gabbro and soda-granite, but the author does not believe that diorite and granodiorite were formed solely in this way. Nevertheless, it is impossible entirely to separate differentiation and hybridization. It is but a step from reaction between early-crystallized minerals and a late acid residue to actual action of acid magma on basic rock.

ACKNOWLEDGMENTS.

The author gratefully acknowledges the award of grants from the Royal Society, the Department of Scientific and Industrial Research, and the Dixon Fund (the latter to defray the cost of chemical analyses). He is indebted to Professor W. T. Gordon for providing facilities for the research; to Dr. A. K. Wells for much kind help and criticism; and to Mr. H. H. Gregory for advice in connection with the field work.

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EXPLANATION OF PLATE I.

Zircon and Apatite Grains from the Mountsorrel Igneous Rocks.

1–10 *Zircon.*

1–2. Gabbro.
3. Diorite, Kinchley.
4. Diorite, Brazil Wood.
5. Diorite, Kinchley.
6. Granodiorite, main Mountsorrel Quarry.
7. Granodiorite, South of Cocklow Wood.
8. Granodiorite, Cocklow Quarry.
9. Granodiorite, Kinchley.
10. Basic granodiorite, Waterworks Dam.

11–20. *Apatite.*

11–14. Gabbro.
15. Basic granodiorite, Quorn House grounds.
16. Granodiorite, main Mountsorrel Quarry.
17. Gabbro.
18. Granodiorite, Rubbish Tip Quarry.
19. Granodiorite, main Mountsorrel Quarry.
20. Granodiorite, Cemetery Pit.

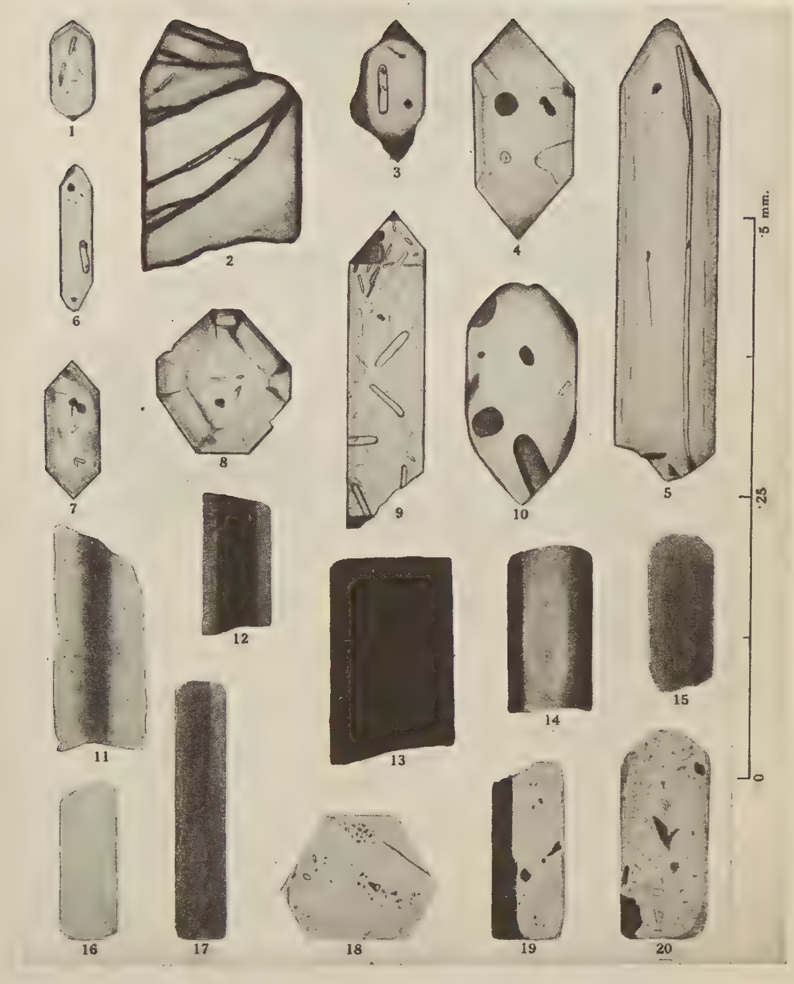
Petrographical Notes on Rocks from the Gulf of Guinea.

By G. W. Tyrrell, A.R.C.Sc., D.Sc., F.R.S.E., F.G.S., Lecturer in Geology, University of Glasgow.

THE following notes refer to a collection of rock specimens made by the late Capt. T. Alex. Barns, F.R.G.S. Along with a summary of the geology of the four main islands in the Gulf of Guinea by the late Prof. J. W. Gregory it was intended to publish them as an appendix to a travel book by Capt. Barns. This book was never published as Capt. Barns was killed at Chicago in a motor accident on the 5th March, 1930. He had, however, already published an account of his journeys in the *Geographical Journal*.[1] Prof. Gregory's manuscript on the geology of the islands cannot now be found. It is felt, however, that the petrographical notes and the two new chemical analyses that accompany them, should be placed on record.

The collection consists of twenty-one specimens, of which thirteen come from Annobon, two from Principe, and six from the mainland of Spanish Guinea (Rio Muni).

[1] "In Portuguese West Africa: Angola and the Isles of the Guinea Gulf," *Geogr. Journ.*, lxxii, 1928, 18–37.



Zircon and Apatite Grains from the Mountsorrel Igneous Rocks.

[*To face p.* 16.

Annobon.—Annobon is the southernmost of the linearly-arranged group of four islands, Fernando Po, Principe, Sao Thomé, and Annobon, which are aligned in the given order from N.N.E. to S.S.W. in the Gulf of Guinea. This line is continued to the N.N.E. on the mainland by Kamerun Mt. The most recent description of Annobon is by A. Schultze (1913),[1] for although Capt. Barns in the above-cited paper states that he visited Annobon, he describes the other three islands but fails to describe Annobon.

According to Schultze, Annobon has an area of about 17 square kilometres. The island consists of basaltic flows with some " yellowish tuff ", and its basement is cut by innumerable basalt dikes which vary in thickness from finger-width to more than 20 metres. A great basaltic crater, Quiovéo, occupies the central part of the island, and the last flow from this focus escapes through a gap on its north-western rim. The appearances suggest that the volcanic activity is quite recent, although there are no historical records. A trachytic plug, the Pico de Fogo, breaks through the northern wall of Quiovéo, and forms a monolithic hill conspicuous because of its white colour. This is stated to represent the only occurrence of trachyte upon the island.

The rocks collected by Capt. Barns on Annobon consist of lavas which fall into two petrographical groups: (1) trachytes; (2) ultrabasic olivine-rich basalts or oceanites, with their glassy representatives limburgites, and two kinds of olivine nodules.

The *trachytes* are compact rocks of whitish colours and chalky appearance, and in some specimens of a porous and friable texture. When studied in thin section under the microscope they prove to consist almost entirely of a clear, transparent orthoclase of the sanidine variety, which occurs chiefly as a mass of minute rectangular crystals forming a groundmass to a few larger phenocrysts of the same mineral. As the analysis (Table I, 2) shows, the feldspar must be soda-orthoclase rich in the albite molecule. The only coloured minerals present are small flakes of biotite, which are always somewhat altered with the production of magnetite grains along the cleavage planes. A little magnetite and sphene may also be present as original constituents. Two of the slides enclose fragments of serpentinized olivine and dark slaggy matter, which obviously represent particles picked up by the lava during its flow over the surface of the ground.

The five specimens of biotite-trachyte, which undoubtedly represent the rocks identified by Gürich as mica-trachyte,[2] differ very little amongst themselves. The only variations are in respect to texture and the amount of biotite present. One of the specimens, however, is bauxitized, with the exception of the larger phenocrysts of sanidine which remain practically unaltered. This is a common mode of alteration of aluminous rocks such as trachyte under tropical conditions.

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[1] " Die Insel Annobon im Golf von Guinea," *Petermanns Geogr. Mitth.*, Jahrg. 59, i, 1913, 131–3.

[2] In A. Schultze, op. cit. *supra*, p. 132.

Oceanite and its slaggy and glassy representative *limburgite* have been separated by Lacroix[1] from basalt proper as varieties which differ from ordinary basalts in their richness in olivine, and the consequent relative abundance of magnesia and ferrous iron. Rocks of this character are now known to be abundant, and are recognized as distinctive members of the volcanic rock suites of oceanic islands, hence the name.

The greater number of specimens from Annobon belong to this group. They are dark grey to black compact lavas which, on inspection with a lens, reveal very numerous small crystals of green olivine, and much less abundant black pyroxenes. In thin section the olivines appear as perfectly fresh colourless crystals, which show with unusual clarity the rectangular cleavages of this mineral. Augite occurs as pale brown, sometimes green crystals, with darker tints of lilac or purplish brown towards their margins, and, under polarized light, exhibits a pronounced zonal structure. The augite crystals often have a spongy appearance owing to the inclusion of crowds of minute particles of groundmass materials. This groundmass consists of an obscure mixture of minute microlites of labradorite, specks of magnetite, and dark glassy matter. When the latter constituent becomes dominant, as it does in the slaggy specimens, we have the rock type which has long been known as limburgite.

Amongst Capt. Barns's specimens from Annobon are two examples of olivine nodules, representing segregations of olivine crystals which are frequently found in ultrabasic types of basaltic lavas. One of these is a pure olivine-rock; the other contains a little augite and magnetite beside the olivine. One of the slides of oceanite lava shows a small segregation consisting of green pyroxene.

Trachyte and oceanite are opposite end-members of the trachybasalt assemblage or kindred of igneous rocks which appears to be characteristic of oceanic islands as well as of regions of crustal tension, uplift, and subsidence. While trachybasalt does not occur in Capt. Barns's collection from Annobon, it is abundant in Sao Thomé and Fernando Po, along with trachytes, trachyandesites, augitites, and limburgites, and also with more richly alkaline types such as phonolite (nepheline and haüyn in Sao Thomé), nepheline-tephrite, and nepheline-basanite.[2] A more extensive collection from Annobon would no doubt reveal the presence of some of these types.

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[1] A. Lacroix, *Min. de Madagascar*, tom. 3, 1923, 49–50. See also G. W. Tyrrell, *Principles of Petrology*, 2nd ed., 1930, p. 129.

[2] W. Boese, "Petrographische Untersuchungen an jungvulkanischen Ergussgesteine von Sao Thomé und Fernando Poo," *N. J. f. Min.*, *B.-B.*, xxxiv, 1912, 255–320. A. F. de Carvalho, "As rochas de S. Tomé," *Publ. Mus. Min. Geol. Univ. Coimbra*, No. 1, 1921, pp. 9–24. (This reference has not been seen by the writer, but he has been able to consult a summary translation made by the late Professor J. W. Gregory. See Addendum. For a review see GEOL. MAG., LIX, 1922, 231.)

Chemical analyses of the two main rock types from Annobon have been made by Messrs. W. H. and F. Herdsman (Table I, 1 and 2).

TABLE I.

	1	A	B	2	C	D
SiO_2	39·20	42·52	38·62	61·55	60·34	62·0
Al_2O_3	12·49	12·90	13·90	21·15	20·69	17·5
Fe_2O_3	3·47	1·53	5·97	1·24	1·53	2·9
FeO	9·48	10·71	8·65	·84	1·15	1·6
MgO	16·52	13·53	11·21	·30	·38	·6
CaO	9·88	10·55	15·54	·65	1·97	1·1
Na_2O	1·98	3·04	2·01	5·31	3·94	6·6
K_2O	1·05	1·03	·57	5·55	8·15	5·9
$H_2O +$	·27	1·25	1·46	1·92	1·38	1·2
$H_2O -$	1·00	·40	—	·86	—	
TiO_2	3·70	2·08	1·86	·40	·62	·4
P_2O_5	·71	·39	·60	·28	—	·1
MnO	·15	tr.	·30	*nil*	—	·1
CO_2	*nil*	tr.	—	*nil*	—	—
S	tr.	*nil*	—	tr.	—	—
(Ni, Co)O	tr.	*nil*	—	*nil*	—	—
	99·90	99·93	100·69	100·05	100·15	100·0

1. Oceanite, III (IV). 6. (3) 4. 4, Annobon Island, Gulf of Guinea. Anal. W. H. and F. Herdsman.

A. Nepheline-basalt, III (IV). 6″. 3. 4, plug in New Red Sandstone volcanic vent, Ashentree Glen, 3 miles N.E. of Patna, Ayrshire. Quoted from G. W. Tyrrell, *Trans. Geol. Soc., Glasgow*, xviii, pt. 2, 1928, 278. Anal. W. H. and F. Herdsman.

B. Limburgite, III (IV). 6. 4. 4, Dakar Peak, Cap Verde, Senegal. Quoted from C. von John, *Jahr. G.R. A. Wien*, xlvi, 1896, 288. Anal. C. von John.

2. Biotite-trachyte, I. 5. 1. 3″, Annobon Island, Gulf of Guinea. Anal. W. H. and F. Herdsman.

C. Aegirine-trachyte, I. 5. 2. ″3. Monte Caffé, Sao Thomé, Gulf of Guinea. Quoted from W. Boese, *N. J. f. Min., B.-B.*, xxxiv, 1912, 259. Anal. W. Lindner.

D. Alkaline trachyte, I″. 5. 1. (3) 4, mean of 21 analyses from Osann-Rosenbusch, *Gesteinslehre*, 1923, p. 328. Quoted from G. W. Tyrrell, *Principles of Petrology*, 2nd ed., 1930, p. 126.

The analysis of oceanite reveals the low silica and the high magnesia combined with relatively low lime characteristic of this group. The nearest chemical analogue to this rock that an extended search has discovered is the nepheline-basalt of a plug in the New Red Sandstone volcanic vent of Ashentree Glen, near Patna, Ayrshire (Table I, A). Nepheline does not actually occur in the Annobon rock, but a calculation of the standard minerals of the norm shows nepheline to the amount of 8·8 per cent. The plutonic representatives of this type of nepheline-basalt, and of the corresponding heteromorphic oceanites, are undoubtedly the kylites (melanocratic olivine-essexites or theralites) of Scotland[1] and of Rapa (Southern Pacific).[2] The nearest West African rock in chemical composition to that of Annobon is a limburgite from Cap Verde (Table I, B) which, however, owing to its predominance of lime over magnesia, must be a glassy representative of ankaramite, the ultrabasic type of basalt in which pyroxenes dominate olivine.

The analysis of biotite-trachyte from Annobon (Table I, 2) is fairly close to that of the average alkaline trachyte (Table I, D), but it has a smaller amount of total alkalies, and especially of soda. It is thus intermediate between trachyte proper and alkaline trachyte.[3] The closest local analogue is an aegirine-trachyte from Sao Thomé (Table I, C) which, however, is much richer in potash than the Annobon rock, and carries aegirine as the principal coloured mineral in place of biotite.

Principe.—Principe is somewhat larger than Annobon, but is smaller than the remaining two islands Fernando Po and Sao Thomé, between which it is situated. According to Capt. Barns[4] Principe is a volcanic island of startlingly strong relief consisting of a range of mountains none exceeding 3,200 feet in height, which runs east and west, not north and south as in Fernando Po and Sao Thomé. This range is "formed of a series of fantastic domed and table-like rock masses and knife-edged craters"; and the photograph given by Capt. Barns in his paper suggests that the domes and monoliths which are there illustrated consist of trachyte or phonolite just as does the similarly-shaped Pico de Fogo on Annobon figured by Schultze. The tabular mountains, on the contrary, most probably consist of basalt.

The two specimens collected by Capt. Barns on Principe are dull, very compact rocks of dark greyish-green colour. In thin section they show crowds of minute needles of aegirine embedded in an obscure, low-polarizing base which seems to be mainly feldspathic. Occasionally identifiable rods of an alkali feldspar are seen, and there are one or two crystals of sphene. These rocks may be identified as belonging to the *tinguaite* family, but since nepheline has not been found in them they may be provisionally regarded as *solvsbergite,* that member of the family which contains little or no nepheline. They have the general aspect of hypabyssal rocks, and may represent the dikes or plugs of trachytic or phonolitic composition which are frequently found injected into volcanic structures composed of lavas of the trachybasaltic or more alkaline kindreds.

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[1] G. W. Tyrrell, GEOL. MAG., 1912, p. 121.

[2] W. Campbell Smith, *Quart. Journ. Geol. Soc.*, lxxxiii, 1927, 323.

[3] See average analyses in G. W. Tyrrell, *Principles of Petrology*, 2nd ed., 1930, p. 126.

[4] Op. cit. *supra*, p. 30.

CONCLUSIONS.

The following paragraph, taken from Capt. Barns's article in the *Geographical Journal* (cit. *supra*, p. 27) appears to have been inspired by Prof. J. W. Gregory's lost manuscript, and may be taken as epitomizing Prof. Gregory's views on the geology of the islands in the Gulf of Guinea. "This chain of volcanic islands in the Gulf of Guinea at one time obviously formed a peninsula jutting out from the active volcanic region of the Cameroons. The islands lie on a submerged shelf protruding from the mainland, marked, however, by deep depressions. There are two such between the three most northerly islands, and they were formed most probably along a line of fracture at a similar geological period and through a similar cause to the other Atlantic islands such as Ascension, St. Helena, and the Cape Verdes. Professor Gregory suggests that this line of fracture, which extends into the lowlands of the Lower Niger, was contemporary with that which formed the Great Rift Valley, as the lavas associated with the latter formation are similar to those of the Guinea Islands."

It may be added that the submarine ridge on which the Guinea Islands are situated is shown on F. von Wolff's map of the distribution of the Atlantic volcanoes,[1] where it is called the "Guinea Schwelle". This ridge is shown as bending slightly to the south-west, and joining the mid-Atlantic swell opposite Ascension Island. St. Helena is situated about as far to the south of the junction of the two ridges as Ascension lies to the west. On the same map the continuation of the line of volcanic islands in the Gulf of Guinea to the N.N.E. with the great Kamerun volcanic zone is well shown. It therefore seems probable that we are here dealing with a tectonic and volcanic unit which must be regarded as one of the main structural features of Africa. Speaking of the Kamerun zone alone, von Wolff writes: "Man hat diesen Streifen als 'west-afrikanischen Graben' bezeichnet und in ihm ein analoges Gebilde zum grossen ostafrikanischen Graben zu sehen geglaubt, der vom Kamerunberg bis zum Tsadsee reicht. Diese Zone ist jedoch kein ausgeprägte Grabenbruch, sondern viel treffender als ein Schollenland zu charakterisieren, das in ein wirres Mosaik von Horsten, Gräben und Senkungsfeldern aufgelöst ist. Auf diesen Dislokationen sind basaltische und trachytische Magmen emporgedrungen und haben eins der ausgedehntesten Basaltgebiete der Erde geschaffen."[2] These observations may perhaps be extended to cover the Guinea Islands. Certainly the petrographic character of the Kamerun region mentioned by von Wolff, namely, the association of basaltic and trachytic magmas, is also characteristic of the continuation of the Kamerun zone into the islands of the Gulf of Guinea, as also of

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[1] *Der Vulkanismus*, Band ii, 2. Teil, Die Alte Welt. 1. Lief. Der Atlantische Ozean, 1931, pl. ii.

[2] Op. cit. *supra*, p. 1061.

Ascension and St. Helena. The basalts are mostly trachybasalts of a decidedly alkaline cast, which are associated with basanites, nepheline-basalts, and nephelinites, whilst the trachytes likewise are associated with phonolites. This great zone of volcanic activity is thus characterized petrographically by what has been called the trachybasaltic kindred.[1] This assemblage of igneous types seems to occur most frequently in oceanic islands and in regions of tension, subsidence, and uplift. The most abundant magma type is a slightly undersaturated basalt which differentiates in one direction through trachybasalt and trachyandesite to trachyte and soda-rhyolite, and in another direction to pyroxene-rich and olivine-rich types such as ankaramite and oceanite. Occasionally pronounced local differentiation gives rise to more richly alkaline magmas producing nephelinite, nepheline-basalt, basanite, tephrite, and phonolite.

Spanish Guinea.—The mainland of Spanish Guinea or Rio Muni is a small territory situated on the coast of the Gulf of Guinea at the mouth of the Rio Muni between French Equatorial Africa and Kamerun. Nothing appears to be known of the geology of this region.

Capt. Barns's collection contains six rock specimens from the mainland of Spanish Guinea, four of which are granite-gneisses, one amphibolite, and the sixth a quartz vein-rock. The gneisses are composed of about equal amounts of quartz and alkali feldspar, the latter mostly microcline. Both minerals exhibit the effects of crushing, the quartz by undulose extinction, the feldspars by bent, discontinuous twin lamellae. Biotite in curved flakes forms the principal coloured mineral; but in one specimen there is a little green pyroxene, indicating perhaps that these rocks may have affinities to the charnockite series which is abundant in other parts of West and Central Africa. In another specimen the feldspar is thoroughly bauxitized. The amphibolite is composed of blue-green hornblende in rude gneissic banding with subordinate quartz. These rocks all seem to be referable to the Archaean continental basement of West Africa.

ADDENDUM.

The paper by A. F. de Carvalho, "As rochas de S. Tomé," cited on p. 18, is so inaccessible that it may be of interest to petrographers to have a summary of the rock-types described. The classification used by de Carvalho is as follows:—

A. Phonolites.

1. Trachytoid phonolite or bostonite with little nepheline.
2. Nepheline-phonolite.
3. Haüyn-phonolite.
4. Phonolites with plagioclase.

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[1] G. W. Tyrrell, *Principles of Petrology*, 2nd ed., 1930, p. 140.

B. Phonolitic andesites [= Trachyandesites ?].

1. Phonolitoid type.
    (*a*) With hornblende.
    (*b*) With hornblende and pyroxene.
2. Basaltoid type.
    (*a*) With phenocrysts of plagioclase—hornblende-trachyandesite (hornblende-cantalite).
    (*b*) Devoid of plagioclase phenocrysts—camptonites.

C. Alkali-basalts.

1. Trachybasalts.
    (*a*) Basaltoids.
    (*b*) Trachydolerite.
    (*c*) Trachybasalt of phonolitoid type.
    (*d*) Passage rocks to limburgite.
2. Nepheline-basanite, phonolitoid.
3. Nepheline-tephrite, basaltoid.
4. Limburgite.
5. Augitite.

Triassic and Pleistocene Surfaces on some Leicestershire Igneous Rocks.

By Frank Raw, D.Sc., F.G.S.

(PLATES II, III.)

THE ancient rocks of Leicestershire may be taken to comprise the pre-Cambrian volcanic and sedimentary rocks of Charnwood Forest, and the igneous rocks intrusive into them, viz. the dacite-porphyrites of Bardon Hill, Peldar, and High Sharpley, etc., the granophyric diorites and porphyrites within and south-west of the Forest and in South Leicestershire, and the Mountsorrel granite or granodiorite. There is reason to believe that all except the last are pre-Cambrian in age: for the last a post-Silurian age seems most probable. These ancient rocks are now exposed through the removal of the Keuper Marl, which had largely if not completely buried them. In glacial times, however, small areas have been reburied under glacial deposits.

These ancient rocks have been exposed to denudation several times: probably for many separate periods of geological history. Each period of denudation had conditions peculiar to itself. And whether under marine or terrestrial conditions; whether by waves, rivers, glaciers; or by air, rain, sun, frost, etc.: whether under arid or humid weathering—a distinctive type of surface has been developed.

Most of these peculiar surfaces have been lost. They were removed either by the same processes of denudation that produced them, or by a later epoch of denudation. When, however, denudation came to an end and was succeeded by deposition, the surface was preserved for later time; and some of these surfaces are still preserved, and are exposed again in the modern progress of denudation and of quarrying. Among those still available are those beneath the base of the Cambrian in East Warwickshire, beneath the Carboniferous Limestone and the Coal Measures, beneath the Lower and the Upper Keuper, and beneath different stages of the Glacial succession. These surfaces are worthy of special study, because often they indicate so strikingly the physical conditions under which they were produced. In the district around Charnwood the sub-Triassic, the sub-Glacial, and later surfaces are or have been well displayed, and I will proceed to illustrate them, limiting myself to the few places that I have inspected. The numerous quarries opened into the hard Charnian, and igneous rocks have mostly been extended beneath the unconformable cover of newer rocks.

THE SUB-KEUPER SURFACE.

(Pl. II, Figs. 2–5, and Pl. III, Fig. 5.)

Beneath the Keuper the ancient rocks, whether Charnian, or diorite-porphyrite, or granite, are surprisingly fresh and undecomposed; and except for a superficial bright red iron stain are in the same condition as the heart of the stone. They were, therefore left at least equally fresh by Triassic weathering. This fact was stressed by Professor Watts [1] and by T. O. Bosworth.[2] Watts also first described the very striking horizontal grooving of the granite of Hawcliff, near Mountsorrel,[3] and attributed it to sand-blast abrasion under the arid conditions of the Keuper.[4] This, however, I am unable to accept. To Triassic age and to sand-wear he attributed also the splendidly polished, and in many cases fluted surfaces of the granite which he collected: some of which he deposited in the Geological Museum of Birmingham University. These, however, he did not find on the granite in situ.[5] Bosworth also in his book on the Keuper Marls around Charnwood describes the "fretted" surfaces of the various igneous rocks beneath the Keuper Marl, and the "fretted nuggets" of these same rocks within it; and ascribed them to sand-blasting of Keuper age. To the same origin and date he assigned also the terracing of the sub-Keuper rock surface, which he recognized at Groby as well as at Mountsorrel, and the polished surfaces, which he found at Narborough and Mountsorrel.[1]

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[1] Watts, W. W., "Charnwood Forest," *Geology in the Field,* Jubilee Volume Geologists' Assoc., pt. iv, 1910, 783.

[2] Bosworth, T. O., "The Keuper Marls around Charnwood," *Leices. Lit. and Phil. Soc.*, 1912, 38; also "The Keuper Marls around Charnwood," *Quart. Journ. Geol. Soc.*, lxviii, 1912, 283.

[3] Watts, W. W., "Note on the Surface of the Mount Sorrel Granite," *Brit. Assoc. Rep. for* 1899, 747; or GEOL. MAG., 1899, 508.

[4] Watts, W. W., "Excursion to Charnwood Forest," *Proc. Geol. Assoc.*, 1902, 379; "Charnwood Forest: A Buried Triassic Landscape," *Geog. Journ.*, 1903, 632; "Notes on the Granite Surfaces of Mount Sorrel," *Brit. Assoc. Rep. for* 1915, 424.

[5] *Geog. Journ.*, 1903, 632.

At the British Association in 1913, when I described sand-polished cliffs and stones of Pleistocene age in the Midlands,[2] I suggested that the polished surfaces of Mountsorrel, which I had not then seen in situ, might prove to be of Pleistocene age. In the following year I visited Croft, Mountsorrel, Markfield, and Cliff Hill. At Markfield and Cliff Hill neither Keuper nor Glacial deposits were seen, and none of the surfaces in question; but at Croft and at Mountsorrel I satisfied myself that the surfaces beneath the Keuper Marl showed no sign of sand-blasting and that the sand-blasted surfaces there found were post-Triassic.

Both at Croft and at Mountsorrel the sub-Triassic surface of the igneous rocks is an irregular one of rounded knobs and hollows. Examined closely, it is seen to be due to fracture across the minerals and is never ground smooth. Frequently there is evidence of it having been produced by exfoliation. Its felspar is superficially stained bright red, and it has red or greenish-white grit, like the skerries, cemented to it by a dolomitic cement. Under a lens and under the microscope the surface of the granite, over quartz and felspar alike, is quite rough and dull. The only gloss is on flakes of biotite or chlorite, which in a sand-blasted surface would not be seen. Sometimes the granite is exfoliating, and on detaching a shell, the surface beneath has exactly the same character—red-stained, rough, and dull. The surface of the quartz even after washing with acid is dull, quite unlike a fresh fracture. This has doubtless caused it to be attributed to sand-blasting. On the other hand the roughness is never ground away; there is never any fluting, i.e. there is no evidence of wind direction; and the glossy rounded surface characteristic of sand-blasting is never present. Two possible explanations suggest themselves: Either (1) we are dealing not with a broken surface but with the irregular sutures bounding the quartz grains; or (2) there has been corrosion of fractured surfaces of quartz under the hand of time. One may remark that the relatively gentle alternating stresses inherent in insolation and the difference in the coefficients of expansion of quartz and felspar and their different directions would tend to localize fractures along sutures. This lends support to (1). In the overlying Keuper Marl are abundant pebble-like bodies with the same character of surface. These are strikingly seen at Cocklow Wood quarry of the Mountsorrel granite; and it is noteworthy that on them the surface is the same all over, which could not be the case had they been sand-blasted.

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[1] Bosworth, T. O., "The Keuper Marls around Charnwood," *Leices. Lit. and Phil. Soc.*, 1912, 28, fig. 16; 41, fig. 25; 21, 34, fig. 21; 29, 33; also *Quart. Journ. Geol. Soc.*, 1912, 282, 284, and fig. 1.

[2] Raw, F., "On the Occurrence of a Wind-worn Rock Surface at Lilleshall Hill, Salop, etc.," *Brit. Assoc. Rep. for* 1913, 493; or GEOL. MAG., 1913, 523.

At Hawcliff, Mountsorrel, in 1914, at the south corner of the quarry the granite rose abruptly into crags which showed a little of the horizontal terracing –horizontal ridges and grooves (see above, p. 24)—but the surface was like the other sub-Keuper surfaces, one of pure fracture. Had these surfaces when seen by Watts been really sand-blasted, they would have been described as polished, for the Keuper Marl preserves the surface so perfectly. On the British Association excursion to Mountsorrel, 12th September, 1933, a similar terraced surface, from which the Keuper Marl had been stripped, was seen on the north side of Cocklow Wood quarry. This surface was again red-stained and rough. Another, but less fresh, was met with on the west side of Castle Hill, Mountsorrel.

There can be little doubt but that these sub-Keuper Marl surfaces are due to insolation, effecting exfoliation; and the horizontal grooving might be attributed to insolation combined with variation of water-level or of Keuper Marl level. Exfoliation would be limited to the part left uncovered, which would be bounded by a horizontal surface. If this was water, exfoliation might be expected to be rapid where sun heat and the cooling effect of lapping water alternated. Hence, I think they may mark the times and the levels, when the change of water-level was slowest.

The same fracture surface characterizes the Cambrian quartzite of Nuneaton beneath the base of the Keuper, and the roundish quartzite fragments within this. Here again the surface of the quartz under the microscope is rough and dull.

The abundant pebble-like stones with such surfaces deserve a name: I suggest *insolilith*. They can be seen in process of formation: upstanding knobs coming to stand on slender stalks before they break off illustrate one mode of formation; while loose angular stones exfoliating illustrate another.

The sub-Keuper surface of the Mountsorrel granite is seen magnified by $2\frac{1}{2}$ in Fig. 5 of Plate III, and an insolilith of the same is seen reduced to $\frac{2}{5}$ in Fig. 4, Pl. II. In Fig. 5 of the same Plate a projecting knob of the porphyrite of Croft is seen with its pale dolomitic crust; and in Figs. 2 and 3 the Mountsorrel granite is overlaid by Keuper Marl with insoliliths.

These characteristically Keuper surfaces are destroyed by modern weathering, the effect of which is to rot the felspars and furnish a carious surface, exceedingly rough.

THE SUB-GLACIAL SURFACE.

(Pl. II, Fig. 6.)

Both at Croft and at Mountsorrel glacial deposits overlie the Keuper Marl and overstep it on to the igneous rock. At Croft a lower red Boulder Clay with Bunter pebbles is overlaid by dark grey Boulder Clay with Lias, Chalk, and flint. The rock surface beneath the Boulder Clay is ground and striated—a Pleistocene surface—and the red skin and dolomitic crust characteristic of the Keuper are lacking.

At Mountsorrel too, in 1914, around the main quarry there had been exposed after removal of Boulder Clay fine examples of glaciated surfaces—ground, bruised and so whitened, and also striated—in marked contrast with the sub-Keuper surface, which can be seen on the lower slopes of the granite under Keuper Marl which there underlies the Boulder Clay. Above the west side under Chalky Boulder Clay the striae ran 17° W. of S. Above the south-east of the quarry, 17° E. of S. and 1° and 6° E. of S. were recorded in different places. Whether these were associated with Boulder Clay containing Bunter material I cannot say.

THE POST-CHALKY BOULDER CLAY SURFACE.

(Pl. III, Figs. 1–4 and 6.)

The Chalky Boulder Clay bore in it and on it several immense boulders of the granite which projected up into a quite different deposit, viz. reddish sand. These glacial boulders exhibited another kind of surface. They were magnificently smoothed and fluted as by wind-driven sand. On the finest specimen the disposition of the flutings suggested a wind from N. 32° E. (Pl. III, Fig. 1). I was, however, given to understand that the block had been slightly shifted by blasting. These surfaces were just like the specimens collected by Professor Watts and attributed to Triassic sand-blasting. This same kind of surface was also exhibited on the granite in situ above the Boulder Clay at the west end of the quarry where the flutings suggested drift from N. 30° E.

Where fresh this surface is in every minute bit of it smooth to the touch. It may be even or uneven: when the latter it may either be deeply pitted or parallel-fluted; and in this case the deep pittings or grooves are as smooth as the projections. It is quite clean, free from clay, from hematite stain, or from dolomitic crust, and free also from rock splinters with air behind. When pitted or fluted the projections consist mainly of the hardest or most resistant minerals, especially quartz, while the hollows follow the felspar and mica; moreover, the detailed form of the surface indicates very clearly the dominant direction of the sand-blast which produced it. Under the microscope the surface still appears smooth, and on the quartz even polished (see Pl. III, Fig. 6, where the fluted surface is × 6). When undisturbed these surfaces are covered not with Keuper Marl, nor with Boulder Clay, but with loose yellowish or reddish sand which may overlie one or other of those deposits.

Study of the different varieties of the surface in the field suggests that they depend largely on the nature of the initial surface, its disposition whether horizontal or vertical, and its aspect and spatial relation to other surfaces. The initial surfaces presented gradations from a fresh joint face practically plane, exposed doubtless by glacial stress and transport, to an irregular decomposed carious surface due to weathering. Steep or vertical surfaces, if their aspect was right, best developed pitted or fluted forms according as the blast met them square or with a glancing incidence. Horizontal surfaces, traversed as they might be by all directions of wind, tended to develop a more even surface (Pl. III, Fig. 4). The distribution of the pittings and flutings on upstanding rocks proves that the sand was carried by a north-east wind, and suggests that this was the dominant wind of the time. In the tips of waste from Mountsorrel so many pieces of sand-blasted granite were found as to suggest that no small part of the surface of the hill of granite was thus affected. But as under modern weathering this surface is destroyed it must have been largely buried in the sand.

In other parts of the granite mass, which forms several hills, sand-blasted surfaces were found abundantly both on the granite in situ and on detached fragments. At Hawcliff, in 1914, this surface was seen on the granite in situ at a higher level than the Keuper Marl reaches, and partly covered in loose sand. Vertical surfaces facing east were markedly pitted or fluted, while horizontal surfaces were ground smooth. At Castle Hill, just above Mountsorrel village, the granite on the east side had been smoothed and fluted and these surfaces were partly buried in soft sand. In the best example (Pl. III, Fig. 2) the flutings suggested drift from N. 60° E. In another on the south side of a gully the flutings ran N. 52° E. On the same hill at the north-west boundary on a rounded mass of granite in situ facing N. 15° W. a salmon-pink felsite vein mostly chipped away by geologists still retains its sand-blast polish, but the granite in which it is intrusive has lost this surface and has apparently lost by weathering $\frac{1}{8}$ in. since it was exposed. This more rapid weathering of the granite than of the felsite had already obtained before the sand-blasting, for the felsite projects nearly $\frac{1}{4}$ in. beyond its contact with the granite. These occurrences on Castle Hill are below the level of the Boulder Clay on Mountsorrel, and had they been pre-Glacial could not have survived glacial erosion.

At Nunckley Hill quarry too, where again Keuper Marl is quite absent, both strongly pitted and strongly fluted sand-blasted surfaces occur on the granite in situ. The surface of this is still largely covered with sand which again encloses numerous sand-blasted fragments of the granite. Cocklow Wood quarry also furnished several examples on loose stones in sand containing flints, that in different places overlies directly both the Chalky Boulder Clay and the Keuper Marl. Here comparison can easily be made between the red-stained insolation surface beneath the Keuper Marl and this post-Chalky Boulder Clay sand-blasted surface. This at present seems the most promising place for fresh exposures of sand-blasted granite in situ.

At Croft too, the evidence, though meagre, was in agreement.

In Croft quarry a wind-polished flint was found, evidence of post-Chalky Boulder Clay sand-blasting; and in Huncote quarry higher than the Keuper Marl and above the porphyrite there is coarse sandy breccia with sand-blasted stones, including the granophyric monzonite of the hill. Seeing such sand-blasted stones are so common, I suggest a name for them—*eoliliths*.

But similar surfaces are spread widely through the Midlands, not only on eoliliths, but on rocks in situ; and they are not known to be associated with deposits older than Glacial, except in a case described by Professor Swinnerton, a surface beneath the Keuper Sandstone in South Nottinghamshire.[1]

The nearest parallel to Mountsorrel is Lilleshall Hill, where also the sand-blasting was only found on the east side, and indicated a strong easterly component in the wind direction. Another parallel is the Hartshill Ridge, on which the Cambrian quartzite has been sand-blasted, where it faces the plain to the north-east.

The surface is sometimes interglacial. This was the case in that described by Lamplugh from the coast of Yorkshire. In several places eoliliths have been found beneath glacial deposits in the Midlands. At Tessal Lane, Northfield, South Birmingham, an exposure this summer showed a great spread of boulders of Cambrian quartzite like that of the neighbouring Lickey Hills strongly sand-blasted and overlaid directly by Boulder Clay with Bunter pebbles.[2] These interglacial sand-blastings can with much probability be correlated with the loess formations of the Continent.

The more superficial glacial drift of the Midlands contains eoliliths in great numbers, and glacial erratics very frequently are magnificently sand-blasted. It is therefore thought by some that the sand-blasting is recent. But I am inclined to think that it is mainly interglacial, because I have hunted for eoliliths along the York and Escrick moraines and in North Yorkshire and have not found them. It is perhaps not improbable that there may come to be recognized as many epochs of sand-blasting in Britain as there are epochs of loess deposition on the Continent.

Hence I attribute the sand-blasting of the igneous rocks of Leicestershire to some period in the interval between the deposition of the Chalky Boulder Clay of the East Midlands and the deposition of the Escrick-York moraines. A later date is deduced for the " Facetted Pebbles in the South Manchester district ", but this area is west of the Pennines, in the Irish Sea basin.[3] That they are still so fresh on such decomposable rocks as granite and porphyrite is due in every case here cited to their having been buried up mostly in the wind-driven sand till modern quarrying operations either removed this or caused it to fall away.

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[1] Swinnerton, H. H., " Periods of Dreikanter Formation in S. Notts," GEOL. MAG., 1914, 208.

[2] This was associated with exfoliation, which had followed the main sand-blasting, and had been followed by a repetition of the same. They were, however, perfectly clean and devoid of red stain, Perhaps the exfoliation was due to frost, rather than sun.

[3] Jackson, J. W., and Jones, O. T., *Mem. and Proc. Manch. Lit. and Phil. Soc.*, lxx, 1925–6.

Though this paper aims at showing that one phenomenon previously taken by Watts as evidence of the Keuper hot desert is instead attributable to a cold desert of the Pleistocene, our belief in hot desert conditions for the Upper Keuper rests, I think, upon very secure evidences. Among these we can cite: the absence of fossils, the deposits of salt, anhydrite, and gypsum; the further evidences of desiccations, such as the sun-cracks and salt-pseudomorphs under the skerries; the dolomite content of the Keuper Marl, and the dolomitization of the Keuper floor, wherever previously calcareous; the insolated character of that floor, and the insoliliths within the Keuper; the freshness of the Keuper detrital minerals; and lastly the red colour of the Keuper deposits, and the hematitization of the iron of the sub-Keuper rocks often to a great depth. The recognition of these desert conditions rests in no small measure on the work of Watts, Bosworth, and other geologists working around Charnwood, and this humble contribution is a direct result of their work.

DESCRIPTION OF PLATES II AND III.

The views were all taken in July, 1914.

PLATE II.

Fig.

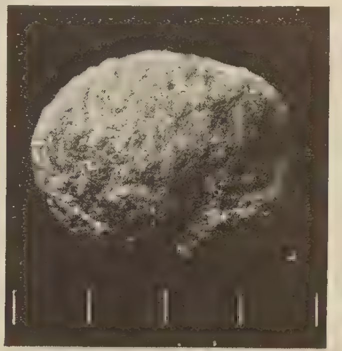
1.—Mountsorrel granite cut by dominant north-south joints, and by east-west joints facing the camera. The north-south joints are stained red. The east-west joints, parallel to which the granite splits more readily, are stained brown and green. The sheet joints, fairly horizontal, are also seen. South side of Cocklow Wood quarry, Mountsorrel.

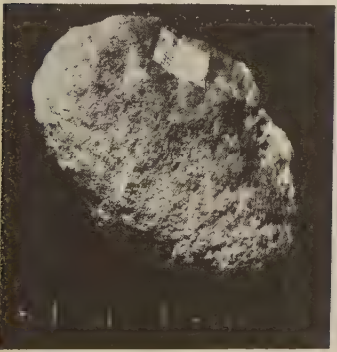
2.—Part of the north face of the same quarry, showing the irregular top of the granite—a Triassic surface overlaid by Keuper Marl with abundant insoliliths. North side of Cocklow Wood quarry, Mountsorrel.

3.—Part of the same quarry face as 2 but further west, showing the exfoliated surface of the granite under the Keuper Marl, which descends into three widened joints. That in the middle of the photo is 2 feet deep. No trace of sand-blasting could be detected on any of the granite surfaces or granite boulders. North side of Cocklow Wood quarry, Mountsorrel.

4.—Typical insolilith of Mountsorrel granite from the base of the Keuper Marl shown in photo 2, exhibiting a rough surface due to cracking under exfoliation, which is attributed to insolation. Cocklow Wood quarry. Reduced to two-fifths.

5.—Typical sub-Keuper surface of the porphyrite (a granophyric quartz-monzonite) of Croft quarry. The surface is boldly rounded due to exfoliation, is rough and without any evidence of sand-blasting, and the light-coloured areas are a pale green dolomitic Keuper encrustation. Croft quarry, Leicestershire. Reduced to one-quarter.

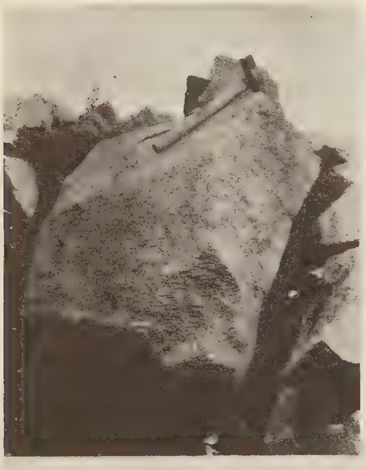




[*Photo F. Raw.*

SURFACES CHIEFLY OF MOUNTSORREL GRANITE:
Figs. 2–5 sub-Keuper; Fig. 6 sub-Glacial.

1



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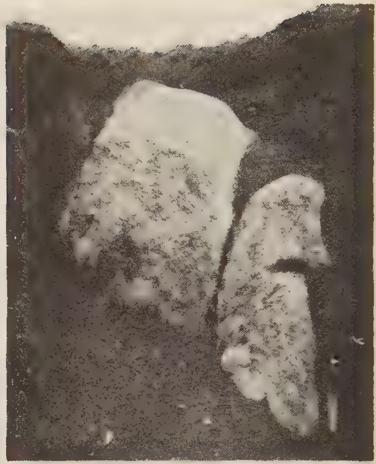

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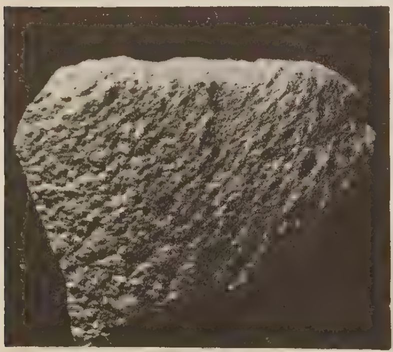

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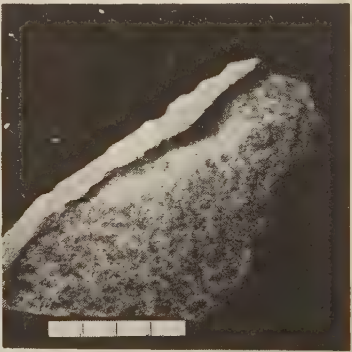

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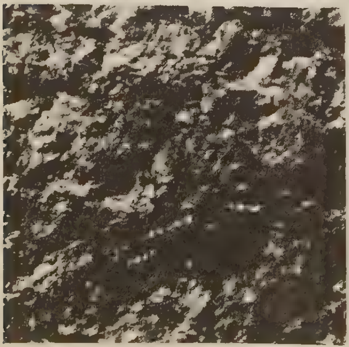

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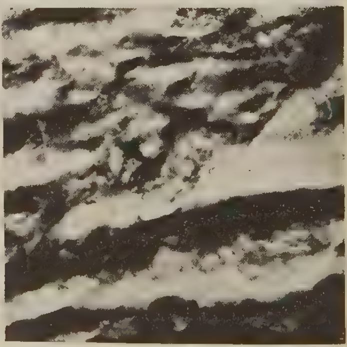

[*Photo F. Raw.*

SURFACES OF MOUNTSORREL GRANITE:
Fig. 5 sub-Keuper; the rest Later Pleistocene.

To face p. 31.]

6.—Glaciated surface of Mountsorrel granite exposed on removal of boulder clay, still in place to the left. The hammer indicates the direction of striae. The surface is planed, bruised, and striated, in contrast with the Keuper and later-Pleistocene surfaces. Mountsorrel, main quarry, above the south side.

PLATE III.

1.—Boulder of sand-blasted Mountsorrel granite resting on Chalky Boulder Clay. The hammer marks the directions of the flutings on that face, which run N. 32° E. The flutings fan out and run across the corner presented to the camera. The block had been slightly shifted as a result of blasting. Mountsorrel, main quarry, above the west side.

2.—The northern of two markedly sand-blasted and fluted surfaces on Castle Hill above Mountsorrel village. The flutings fan out, but on the crest they run N. 60° E. Castle Hill, Mountsorrel, mid-length, east side.

3.—Sand-blasted and fluted granite. Hawcliff quarry, Mountsorrel. Collected W. W. Watts. Birmingham University Museum. Reduced to one-fifth.

4.—Smooth sand-blasted granite from the same quarry. It probably lay horizontally. Hawcliff quarry, Mountsorrel. Collected W. W. Watts. Birmingham University Museum. Reduced to one-sixth.

5.—Sub-Keuper red-stained surface of granite. Compare with Fig. 6. Hawcliff quarry, Mountsorrel. × $2\frac{1}{2}$.

6.—Pleistocene sand-blasted surface of granite from Pleistocene sand. Compare with Fig. 5. Top of Hawcliff quarry, Mountsorrel. × 6.

The Production of Normal Rock Types by Contamination and their bearing on Petrogenesis.

By S. R. Nockolds.

IN a recent paper[1] the author attempted to explain something of the mechanism of contamination in acid magmas, but nothing was said about the tendency of contamination to produce normal rock types. It is to repair this deficiency that the present communication is presented.

We shall take, for the most part, the production of normal rock types by the assimilation of basic material (gabbroic, doleritic, or noritic in nature) in an acid magma, because the writer, for reasons which will become apparent later, believes this to be the most important case. A good many examples of this, on a small scale, have been described and the reactions which go on here are probably better known than for any other. We find that the following types of reaction, or reaction series, have all been noticed at one time or another :—

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[1] S. R. Nockolds, *Journ. Geol.*, xli, 1933, 561–589.

olivine → rhombic pyroxene → colourless amphibole → brown amphibole → green amphibole → biotite → (green mica → chlorite).

monoclinic pyroxene → new monoclinic pyroxene → brown amphibole → green amphibole → biotite → (green mica → chlorite).

monoclinic pyroxene ↗ rhombic pyroxene → biotite.
↘ basic plagioclase → acid plagioclase.

plagioclase → more acid plagioclase.

As by-products in these reactions we have such minerals as magnetite, ilmenite, sphene, and apatite.

Such reactions, proceeding with the aid of alkalies, alumina, and volatiles from the acid magma, gradually transform the basic material whether as contact rock, xenoliths, or xenocrysts, into phases more suitable to its acid environment. Various steps in the reaction series may be omitted as in the direct conversion of pyroxene to biotite and so on. At the same time such reactions induce a reciprocal effect in the acid magma which enables new phases to crystallize in keeping with the new phases produced in the basic material. Thus, if reciprocal reaction can be maintained for any length of time all the new phases present in the xenolith or contact rock will be represented in the acid magma either potentially or in reality. The introduction of quartz and alkali felspar into the basic material by mechanical means not only disintegrates it but allows it to attain exactly the same mineral composition as that of the enveloping magma. The further this disintegration goes the nearer the expanding basic material approaches to the surrounding acid magma. In the final stage they are, of course, more or less indistinguishable. Now all the reaction series which are set in motion during this incorporation of basic rock are those of normal type which we are accustomed to regard as the result of progressive and gradational differentiation. If reciprocal reaction can go to completion and if mechanical disintegration can occur then normal rock types must result. Such rock types as diorite would be expected from basic material affected to a small extent by acid magma; tonalitic types may represent basic material more highly affected or the acid magma basified by reciprocal reaction and the strewing about of altered basic material, whilst granodioritic types, in the main, probably represent the acid magma basified to a somewhat less extent. All these types might be expected to arise from the incorporation of original basic rock by an acid. quartzo-felspathic magma. The important element is undoubtedly time, and sufficient time should be available in many intrusions at reasonable depth, particularly as there is little doubt that plutonic acid intrusions have a long crystallization period, and as, in some cases at least, the basic material is probably derived from depth and is in contact with the magma for a long time. Thus we may say, with a fair degree of confidence, that there are no inherent difficulties present in the production of normal rock types (such as those mentioned above) by the assimilation processes which we have just briefly outlined. This is merely another way of viewing a matter which has already received attention from other investigators. For instance, Brammall and Harwood [1] find xenoliths in the Dartmoor granite, which range petrographically, "from diabase and quartz-diorite (both hornblende and biotite varieties) to granodiorites—with related porphyries, microdiorites, etc. On further modification they merge into granites." Tyrrell [2] notes homogeneous diorite and quartz-diorite in Arran due to the solution of gabbroic rocks in granite magma. Thomas and Smith,[3] when dealing with the igneous xenoliths in the Trégastel Ploumanac'h granite, find that "the types within the area of basic rocks approximate in composition and structure to a whole range of igneous rocks of a normal differentiation series, but we believe them to be actually the result of hybridization brought about by the action on the original ultrabasic olivine norite of that part of the intruding granite which was still fluid or volatile at the time". Indeed, anyone familiar with recent literature on the subject cannot fail to be impressed with the number of intrusions, once thought to be normal, which are now known to be the result of assimilation, not to mention the number of "normal" intrusions known to be contaminated, but which have not yet been studied in detail.

Another objection sometimes raised is that, even if contamination can produce normal-looking rock types, these types will be chemically abnormal. The variation diagram of the Ardnamurchan tonalite-monzonite series [4] shows that this is not the case. This variation diagram is closely comparable with the variation diagram of the Lower Old Red Sandstone intrusions of Scotland,[5] for instance, the one of the Garabal Hill complex, figured by Harker.[6] The writer has started work on this complex and it will be interesting to see if evidence of contamination is forthcoming in that region as well.

We must admit, therefore, that the intermediate rock types, diorite, tonalite, and granodiorite, may arise from the interaction of an acid quartzo-felspathic magma with solid basic igneous material.

When we come to consider the field occurrence of such types we find a most striking absence of them in all sills and laccoliths which are supposed to show gravitative differentiation, a fact on which Daly [7] has already remarked. On inspecting a list of such intrusions (such as Table 40 in Daly's book just mentioned), it is noticeable that they can be divided into two groups, those which show clear evidence of the control of gravity and those which do not. The only types which can be safely assigned to the former are basic magmas, which give an olivine rich phase towards the bottom with a somewhat more acid phase towards the top, and some highly fluid alkaline basic magmas which yield olivine rich phases and such types as teschenite. The other varieties in which an acid and a basic magma are associated seem, in almost every case, to be due to successive injection and such transitional types as may be present are invariably of hybrid nature. This fact was long ago recognized by Harker.[1] In many of these latter composite intrusions, again, we see clear evidence of gravitative differentiation in the *basic* member with the production of pyroxenite, peridotite, dunite, or anorthosite. From such intrusions we obtain no evidence of progressive differentiation with the production of intermediate types, and yet these are the intrusions from which, according to Daly,[2] " we obtain first-rank data on the problem of differentiation in general." From such intrusions we can reach two important conclusions. In the first place basic magmas (yielding gabbro or norite on solidification) may show gravitative differentiation with the production of olivine-rich and anorthositic phases. In the second place there is clear evidence that differentiation in intercrustal magma basins yields two contrasted magma types, acid and basic. These are injected successively, the basic member invariably coming first. Instead of progressive differentiation we have what we may term contrasted differentiation. The normal magma series of Mull[3] and Ardnamurchan[4] offers similar evidence. In the Plateau type the residuum left over when the bulk of the rock has crystallized is of very contrasted composition. Similarly, the remaining types have a sharply contrasted residuum of quartz and alkali-felspar culminating in the acid type which is dominantly composed of these minerals. Here, again, there is no sign of progressive differentiation in its accepted sense. The intermediate types are not types progressive from basalt (or gabbro) to rhyolite (or granite) but are, essentially, rocks of basaltic type with a varying amount of interstitial granophyric material.

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[1] A. Brammall and H. F. Harwood, *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 202.

[2] G. W. Tyrrell, "Geology of Arran," *Mem. Geol. Surv. Scot.*, 1926, 169–178.

[3] H. H. Thomas and W. C. Smith, *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 286.

[4] "Geology of Ardnamurchan, etc.," *Mem. Geol. Surv. Scot.*, 1930, 88.

[5] Op. cit. 91.

[6] A. Harker, *Natural History of the Igneous Rocks*, 1909, 129.

[7] R. A. Daly, *Igneous Rocks and the Depths of the Earth*, 1933, 459 and 454; also Table 40, 334–7.

Bowen[5] would account for the absence of true intermediate types in the gabbro-granophyre association by means of high fractionation in the plagioclase so that the dioritic phase is normally only present in certain zones of the crystals. We maintain, on the contrary, that high fractionation only occurs where the acid material is in definite contact with what was already solid basic material, that is, where hybridization had begun. In other words, high fractionation can be proved to occur where acid material starts to react with solid basic material, and in this connection it is significant to note that the rocks which show highest fractionation are, in general, micropegmatitic gabbros, diorites, and tonalites—all types which we have already learned to expect as products of this type of contamination. Thus, if these types are normally hybrids, this high fractionation is what we should expect. It is difficult to see why these types should be singled out for high fractionation during progressive differentiation. If, on the other hand, it is argued that acid material should be expected in such rocks as micropegmatite-bearing gabbros and is due to normal progressive differentiation and, as a result, would be expected to react with the earlier solid phases in accordance with the reaction principle as applied by Bowen, then contamination between solid gabbroic material and an acid magma is only a case of deferred progressive differentiation and must, in consequence, yield normal rock types. The theory of crystallization-differentiation is not in question, only the uses made of it. It has been used to account for the production of progressive types when, in those cases where this mode of origin has clearly been dominant, the evidence points to the separation, at an early stage, of two fractions, basic and acidic, which may later react. As in all cases the basic material solidifies before the acidic,[1] any reactions which go on are essentially those of an acid magma on solid basic material, that is, they are contamination processes. The idea of contrasted differentiation is further emphasized by the occurrence of composite dykes and by the segregation veins of lavas which are either basic or of sharply-contrasted acid nature.[2] Again, Rogers and du Toit [3] have mentioned the abundance of small quartz-orthoclase veins cutting the Karroo dolerite sheets. Consequently, the main problem in differentiation does not arise in connection with gradational types but with contrasted types.

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[1] A. Harker, *Journ. Geol.*, xxiv, 1916, 554.

[2] R. A. Daly, loc. cit., 333.

[3] " Tertiary and Post Tertiary Geology of Mull, etc.," *Mem. Geol. Surv. Scot.*, 1924, 14–21.

[4] " Geology of Ardnamurchan, etc.," *Mem. Geol. Surv. Scot.*, 1930, 80–5.

[5] N. L. Bowen, *Evolution of the Igneous Rocks*, 1928, 90–1.

Why should not this type of differentiation also occur in other intrusions ? On theoretical grounds alone it seems an extraordinary thing that contrasted differentiation should be the rule in many laccoliths, sills, and dykes, and yet should apparently be lacking in others. It is not a question of size or form of intrusion. Some very large intrusions are composed of contrasted members, whilst some quite small laccoliths may consist of a graduated series of intrusions.

The writer believes that in many major and composite intrusions the same type of differentiation is at work. What is more natural than that, in this type of intrusion as well, a basic injection is followed by a sharply-contrasted acid one ? Such a basic (gabbroic or noritic) intrusion would, in many cases, now form an outer ring and roof to the intrusion. We should not expect necessarily to find it in an unaltered condition because, in the normal course of events, it will have been acted upon by the later acid material.[1] Such basic margins are a common phenomenon, sometimes gabbroic or noritic, sometimes dioritic, and have often been supposed to represent the original magma, chilled before differentiation in situ could commence. The alternative suggestion is here made that such material represents an earlier basic intrusion in all cases. This earlier intrusion is later overwhelmed by the acid injection which becomes modified by reaction with the basic material to produce such types as tonalite, granodiorite, and so on, types which we have already seen can be most readily produced by such a process. This suggestion has already been made in less detail in a previous paper,[2] and has been independently and tentatively put forward by Thomas and Smith[3] in the following words : " Without multiplying examples we can say that the bulk of the hybrid mass at Trégastel consists, where exposed, of monzonitic and tonalitic types similar to those intimately associated with granitic masses, such as the Old Red Sandstone granites of Scotland and elsewhere. With this in mind, we suggest, tentatively, that tonalitic and monzonitic margins to granitic masses may be due to the hybridizing influence of the granitic magma upon an earlier plutonic rock of basic or ultrabasic composition which once formed part of the same complex but of which all superficial traces may have disappeared. It appears to us, in fact, that many such occurrences can be best explained as quasi-composite intrusions in which the earlier portion was of a hybrid nature, and that this was followed without break and largely replaced by uncontaminated granite." Taylor and Gamba[4] have, more recently, expressed much the same view.

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[1] "Geology of Ardnamurchan, etc.," *Mem. Geol. Surv. Scot.*, 1930, 101.

[2] W. Q. Kennedy, *Amer. Journ. Sci.*, xxv, 1933, 239–256.

[3] A. W. Rogers and A. L. du Toit, 13*th Ann. Rep. Geol. Comm. Cape of Good Hope*, 1908, 105.

In some cases, however, granodiorites, etc., occur in intrusions where no such obvious basic rock is present, and, at first sight, this militates against the view that such rocks in such an environment are due to contamination effects. It does not necessarily do anything of the sort. Several cases of such intrusions have been described where the granodiorite or other type has been proved to have been due to contamination with basic igneous rock and yet no such material is now visible.[5] Xenoliths (" basic segregations ") have in these cases given the clue, and the original basic material must either have formed the roof (now eroded away) or else be lying at a lower level so that the acid material broke through it on its way up. Much the same argument can apply to such things as composite bathyliths and laccoliths where there is a series of gradational intrusions with sharp contacts against one another. Here there would be a series of acid injections following the basic one. The first would be contaminated with the basic material which formed the roof or through which it broke. The next acid injection would be contaminated largely with the first contaminated injection and so on. This would be especially the case in ring intrusions. In this way each intrusion when solid would appear to be more acid than the last, a constant feature of such composite intrusions.

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[1] See, for instance, R. H. Rastall, *Quart. Journ. Geol. Soc.*, lxii, 1906, 265.

[2] S. R. Nockolds, GEOL. MAG., LXIX, 1932, 451.

[3] H. H. Thomas and W. C. Smith, *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 293.

[4] J. H. Taylor and E. A. Gamba, *Proc. Geol. Assoc.*, xliv, 1933, 372.

[5] A. Harker, *Quart. Journ. Geol. Soc.*, lii, 1896, 320–330. W. J. Miller, *Univ. California Bull.*, Geol. Dept., xx, 1931, 331–360. S. R. Nockolds, *Min. Mag.*, xxii, 1931, 494–509. S. R. Nockolds, GEOL. MAG., LXIX, 1932, 433–452.

If the hypothesis of contrasted differentiation proves to be correct there is another important point which can be conveniently dealt with here. We have already seen that the acid magma is fluid for some time after the basic portion has become solid. Indeed, it seems most probable that the solidification of the basic portion is necessary to produce the acid residuum. Therefore in the magma reservoir where this contrasted differentiation occurs the acid magma may be in contact with solid basic rock for some little time before its intrusion to a higher level. Contamination will occur and both the basic and acid material will be reciprocally modified. The basic material, being solid, will of necessity remain in place, but the contaminated acid magma, being still mainly liquid (though it may contain xenocrystal and xenolithic material in the solid), is capable of intrusion at a higher level. In this way we may also have intrusions of tonalite and granodiorite which represent the original quartzo-felspathic magma contaminated, as it were, at the source.

Up to the present we have only dealt with the production of intermediate rock types by the reaction of solid basic igneous rock with an acid aplogranitic magma. Kennedy's work, however, points to contrasted differentiation following more than one course.[1] With slight differences in the composition of the basic magma the latter may be accompanied by either an aplogranitic magma or a syenitic type. This syenitic magma, by reacting with solid basic igneous rock, could presumably give the series gabbro (olivine bearing) → kentallenite → monzonite → syenite → aplosyenite in the same way that granite magma gives the series gabbro → diorite → tonalite → granodiorite → granite → aplogranite. If such contrasted differentiation could go a little further and produce a nepheline-syenite magma we should get such intermediate types as essexite and so on. Examples where reaction between solid gabbro and a pulaskite magma have produced umptekite have been described by Clapp[2] and the type essexite has been known to be a hybrid for some time.[3]

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[1] W. Q. Kennedy, *Amer. Jour. Sci.*, xxv, 1933, 239–256.

[2] C. H. Clapp, *U.S.G.S. Bull.* 704, 1921, 89.

C. H. Clapp, ibid., 124–6.

It is now evident why such stress was laid at the beginning of this paper on the importance of the reactions which proceed when solid basic igneous rock was enveloped in acid magma. If these views on contrasted differentiation are correct, such reactions are a common phenomenon in all intrusions showing gradational intermediate rock types. This should not suggest that the possibility of sedimentary contamination in acid magmas is ignored, but it must be regarded, in the general case, as being of subordinate importance. Argillaceous rocks which are not particularly high in alumina should have an advantage over other types. They need comparatively little reciprocal reaction to stabilize their mineral assemblage and the production of biotite often induces planes of weakness which help the first stages of mechanical disintegration. With highly aluminous argillaceous sediments and calcareous rocks conditions are somewhat less favourable and normal rock types should be correspondingly more difficult to produce. Quartzites, on the whole, appear to be resistant and may remain when other rock types have been incorporated to a great extent.[1] In the case of many argillaceous rocks and some sandstones, the magma may add to its liquid by direct solution of minerals low in the reaction series, such as quartz and potash felspar. Since such solution is endothermic it is limited, but may be sufficient to give the residual liquid a new trend.[2]

Whilst we have confined ourselves here, for the most part, to the action of acid magma on basic igneous material, it should be remarked that the reverse process must play a part, more particularly in depth. Most bodies of igneous rock which are visible seem rather to give evidence of an acid magma as the active agent, but at greater depth basic magma must attack the sial rocks [3] and, in this case, true solution may take place. Here, the reactions are endothermic, and unless crystallization is to intervene such solution as takes place must be due to superheat. If contrasted differentiation is the rule, then this would only serve to increase the amount of the acid member, though it might also alter its nature to some extent, depending on the nature of the material dissolved.

Briefly then, we believe that such differentiation as can be shown to occur is of what may be termed contrasted type, leading to the separation, in intercrustal magma basins, of a basic and an acid magma of varying type. Incidentally, we may note that the idea of contrasted differentiation accounts for the prior intrusion of the basic type. If, as we believe, the basic material in the magma reservoir solidifies, leaving a mobile acid residuum, then the basic intrusion represents a portion of the basic material at a time when some of it, at least, was still liquid. The acid residuum could not be intruded first for the simple reason that it was not there, and it is not until solidification of the basic material takes place that the acid residuum can be intruded as a distinct later injection. After injection gravitative differentiation may affect the basic member leading to the production of such types as picrite, peridotite, dunite, and anorthosite. It may well be, too, that this crystal settling helps to produce the acid magma in the intercrustal magma basins. The point to which attention is drawn is the lack of intermediate rock types in all cases where some sort of differentiation is clearly involved. It is suggested that those intrusions which show intermediate types are also due to an intrusion of basic magma followed at a later date by one or more injections of acid magma, which, by reacting with solid basic rock in situ or at depth, produce the intermediate types.

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[1] O. H. Erdmannsdorffer, *Fortsch. v. Min.*, etc., v, 1916, 198. C. Barrois, *Proc. Geol. Assoc.*, xvi, 1899–1900, 127–8.

[2] A. Brammall and H. F. Harwood, *Quart. Journ. Geol. Soc.*, lxxxviii, 1932, 228–9.

[3] See, for instance, A. Holmes, GEOL. MAG., LXVIII, 1931, 241–255.

Recent writers[1] have rather favoured the view that, in many instances, differentiation may follow assimilation. Some, again, believe that basic magma is the active agent in incorporating material and producing intermediate types. Here, on the other hand, the procedure is reversed. Differentiation is supposed to occur before assimilation comes into play and the acid magma is maintained to be the active agent in producing the intermediate rock types.

We have more or less confined ourselves in this discussion to the plutonic rocks, as they give the clearest evidence of contamination. The dyke rocks can hardly be called upon to support or refute the conclusions drawn, as little serious work has yet been done on the intermediate types. Lavas open up a different problem, and the writer is not competent to deal with them. It is, however, interesting to find that the cognate xenoliths of trachytes and acid andesites are of contrasted types.[2] On the one hand we have the sanidinites and on the other the diorite-diabases which, from the descriptions, appear to be slightly modified gabbros or dolerites. In the augite andesites only these latter are present. Thus, in the more acid types we again see signs that the differentiation in depth had produced two contrasted products, basic and acid.

Finally, it may be admitted that some parts of this paper are of somewhat speculative nature. Future research will no doubt show whether the idea of contrasted differentiation is more than a working hypothesis.

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[1] R. A. Daly, *Igneous Rocks and the Depths of the Earth*, London and New York, 1933. A. Brammall, GEOL. MAG., LXX, 1933, 97–107.

[2] A. Lacroix, *Les Enclaves des Roches volcaniques*, 1893, part ii, 351–545; part iii, 617–635.

REPORTS AND PROCEEDINGS.

British Association, Leicester, 1933.

Abstracts of Paper read in Section C.—Geology.

Professor W. S. Boulton: "Discussion on St. George's Land and the shore-lines of the Midland Barrier during Carboniferous times."

Name proposed by Jukes-Browne for the continuous tract of land in early Devonian time extending from Wales across St. George's Channel to eastern and central Ireland. Prolonged erosion of this part of the Caledonian continent was followed by submergence ushering in the Carboniferous. The delimitation of St. George's Land during this period is the main subject under discussion.

Repeated oscillatory movements during the Carboniferous and Permian shifted the shore-line, so that it is necessary to refer the land margin at any place to the particular time-division when it so stood. The "Mercian Highlands" of Midland geologists are the eastern extension of St. George's Land.

A map is exhibited showing the shore-lines in early Tournasian and late Viséan times, and also the areas where Millstone Grit (*sensu stricto*) and Coal Measures were presumably not deposited. The points specially referred to are:—

(1) The advance of the shore-line northward followed by retreat southward in the South-West Province during the Avonian, and the southward advance in the Midland Province during the Viséan.

(2) The land boundaries in the Leicester area deduced from outcrop and borehole evidence. A possible sea connection west of Leicester between the Midland and South-West Provinces in Viséan time.

(3) Evidence from the pebbles and breccia-fragments of Permian (Enville) beds points to eroded Avonian under the Triassic cover of the Midlands.

(4) A brief summary of evidence from borings as to the extent of concealed Coal Measures between the Birmingham and Leicester areas.

Dr. T. Neville George: "The Carboniferous shore-line in South Wales."

The general Armoricanoid trend of the South-Western Province was established in pre-Carboniferous times, and the Carboniferous sediments accumulated in an oscillating geosyncline to the south of St. George's Land.

Though generally the Lower Limestone Shales are conformable with the underlying O.R.S., they locally transgress, and probably overlap northwards. Thus the shore-line at the commencement of the Carboniferous can be fixed, and its movements in Lower Avonian times deduced.

The intra-Avonian unconformity, visible between the Vale of Neath and Kidwelly, indicates a southward retreat of the shore-line in C_2—S_1 times, followed by a re-advance, causing S_2 beds to transgress probably down to the O.R.S.

In D times the shore-line lay beyond the existing coalfield, though not far distant to the north. At the close of the Avonian, regional emergence accounts for the unconformity beneath the Millstone Grit; while the overlap of higher goniatite zones over lower ones suggests an embayment in the mid-portion of the North Crop between two southward-extending headlands.

The east to west trend of the Armoricanoid axes was modified in places by transverse structures which had considerable effect upon sedimentation and coast-line configuration during the Carboniferous period.

Dr. E. Neaverson.

The Carboniferous Limestone of Flintshire and Denbighshire forms a fringe dipping off various zones of Lower Ludlow rocks which formed the Carboniferous land surface in this part of St. George's Land. West of the Denbighshire Moors the great Ordovician tract of Snowdonia extends north into Anglesey. Carboniferous rocks occur in the eastern part of this island and on the southern shore of the Menai Strait. The ancient shore-line in North Wales is now modified by marginal faulting of comparatively slight effect as a whole.

The limestone often rests on a basement of red conglomerate and sandstone containing water-worn boulders of older rocks. In Anglesey these are mainly pre-Cambrian and Ordovician rocks of local origin. Around the Denbighshire Moors the red beds contain abundant boulders of Upper Ludlow flagstone not known *in situ* in North Wales, but a former northward extension from the type-area is indicated. The junction of basement beds and limestone corresponds approximately with the base of the Dibunophyllum zone, thus dating the Carboniferous transgression from the north.

The Carboniferous Limestone is formed almost entirely of marine organic debris; hence peneplanation of the adjacent land mass is inferred, or perhaps a cliffed plateau protected against marine abrasion by offshore shoaling.

In the Vale of Clwyd the lithology of the D_1 limestones suggests a landlocked bay with slight tidal range. There is some evidence of overlap at the southern end of the Vale, though nothing higher than D_1 occurs on the western side. The present Clwyd Range was possibly separated from the western massif in D_2 times, and there was probably an extension up the Dee Valley to Corwen in D_3 times. The occurrence of knoll-limestones in North Flintshire is noteworthy.

In Flintshire the Holywell Shales have yielded marine faunas representing several goniatite zones. Above these are typical

Coal Measures which connect with the Midland Coalfields. In the Vale of Clwyd the limestone is overlaid by the Purple Sandstone, usually ascribed to the Lower Coal Measures. Coal Measures of limited extent are known under the Drift in Anglesey.

Carboniferous rocks were probably never deposited on Snowdonia, the Denbighshire Moors, and the Clwydian Hills. The western extension of St. George's Land across the Channel to Ireland is questionable.

Mr. T. Eastwood.

South Staffordshire furnishes examples of proximity to land during Upper Carboniferous times—the " Silurian banks ", extending as north-to-south peninsulas or islands to the north of St. George's Land. These banks were completely submerged before the Upper Coal Measures were deposited, though land still occurred to the south as is evidenced by the overstep of the Halesowen Group and by other facts.

In Warwickshire there was land, probably an island, north of Nuneaton. South of Nuneaton basal Coal Measure Shales rest upon Cambrian Shales indicating deposition in quiet waters some distance from a shore line. Later, at Dosthill, an island of Cambrian Shales contributed breccia to the Etruria Marls, while in the same locality the Productive Measures show few signs of proximity to land. The Cambrian Shales also contributed material to the Etruria Marls at Nuneaton ; but farther south the latter formation is barely distinguishable from Productive Measures, and this suggests a northerly provenance, though land probably lay some distance to the south and furnished material for the Corley conglomerates.

Between the Warwickshire and Leicestershire Coalfields the Trias rests on older rocks probably folded along meridional axes of pre-Triassic date. In borings at Chilcote and Desford rocks were encountered which may be interpreted as shore-line deposits.

Dr. Frederick Walker : " The crinanite dike of Maiden Island, Oban."

The bulk of Maiden Island (about 1½ miles north-north-west of Oban) consists of a north-north-west crinanite dike of great breadth and considerable diversity of composition. The west contact of the dike is not visible, but the eastern one shows a junction with a quartzite conglomerate. The length of the visible portion of the dike is just under 400 yards, while the greatest breadth is 125 yards. The crinanite occurs as medium-grained and very coarse varieties which have sharp, unchilled junctions and segregation veins are abundant. These veins include felspathic, zeolitic, and picritic types. The last type occurs as a contemporaneous marginal modification, and thus affords an interesting problem in differentiation. The mutual relations of the various modifications are discussed in this paper.

Professor G. Hickling: Discussion on "The origin of red sedimentary rocks."

There has long been almost universal agreement that "red rocks" are of non-marine origin; but the exact conditions under which they have been formed are still open to discussion. They show two marked facies: unstratified sandstones and red marls of peculiar composition which often contain saline deposits. Normal limestones are absent, but magnesian limestones may be developed. Breccias and conglomerates of several unusual types are commonly found. Fossils are rare and occur sporadically in very restricted areas. Except in the occasional magnesian limestones, which may yield stunted marine forms, the fossils are restricted to fishes, land vertebrates, and a limited flora. Long duration of stable conditions is indicated by the occurrence of faunas of widely different ages in a sandstone mass without any determinable stratigraphical break between them. The red coloration is attributable to prolonged exposure of the sediments above the ground-water level, though they may have been subsequently distributed and deposited by water. It is aided by the total absence of carbonaceous colouring matter which results from a restricted flora and the complete oxidation of any organic remains. Red rocks may show a lateral passage to a marine facies, usually with an intermediate zone of alternating conditions. It is suggested that the rocks are the product of arid or semi-arid delta or flood-plain conditions, and that the explanation of the different types of deposit is to be sought mainly in variations of humidity and temperature, coupled with the effect of earth-movement in bringing the surface of deposition above or below the level of the ground-water.

Mr. J. H. Taylor: "Contribution to the petrology of the Mountsorrel igneous complex."

The paper deals with two aspects of the complex which have received little attention: (1) the nature and characteristics of the accessory minerals; and (2) the processes by which the several members of the complex were formed and emplaced.

Under (1) some twenty mineral species are recorded from the area and described in detail, particular attention being given to the widespread and varied zircon and apatite. Points of special significance are the corrosion of many of the zircons, and the occurrence of dark, sometimes almost black, apatites.

Under (2) the view is expressed that both granodiorite and quartz-mica-diorite are of hybrid origin, resulting from the action of acid magma on basic rock. The latter was almost certainly the gabbro of Swithland reservoir, while some indication of the nature of the acid magma is afforded by a thin marginal facies of the granodiorite that has the composition of alkali-granite. The granodiorite was formed below present ground level, and was subsequently injected into the position it now occupies.

Three new chemical analyses are quoted and discussed, and comparisons are made with rocks of the Channel Islands, Dartmoor, and the Isle of Man.

Dr. F. Raw : "On the Triassic and Pleistocene surfaces developed on some Leicestershire igneous rocks."

The well-known fluted and polished surfaces exhibited by some of the Leicestershire igneous rocks have long been regarded as dating from the Triassic period and as bearing evidence of formation by natural sandblasting under desert conditions. The author has reached the conclusion that these features are here due to the Pleistocene glaciation.

Dr. L. S. B. Leakey : "The age of part of the Rift Valley in Kenya."

In East Africa, work during the past seven years has thrown much new light upon the age of the Great Rift Valley, which was formerly considered to be an event of Mio-Pliocene age, with only small secondary movements during the Pleistocene.

On the new evidence it would appear that the greatest period of faulting, when faults of a throw of over 1,000 feet took place, occurred during the latter part of the Pleistocene, long after man was in the country.

The evidence is discussed and compared with similar evidence from the other parts of the Great Rift Valley, both north and south of East Africa.

Professor A. C. Seward, F.R.S. : "The past and present floras of the Kerguelen Archipelago."

The occurrence of the fossil coniferous wood in beds believed to be Tertiary in Kerguelen Land has long been known. A few years ago Dr. de la Rue collected several specimens of impressions, the best of which are foliage shoots and cone scales of *Araucaria* ; he found also fragments of ferns and imperfectly preserved leaves of Angiosperms and other plants. A general account of the geological and physical features of the Archipelago is given, and the main features and geographical relationships of the present flora are discussed.

A brief description is given of the fossil plants, the age of which is believed to be Tertiary. Special attention is paid to the geographical range of present and past representatives of the genus *Araucaria.* The main purpose of the paper is to draw attention to phytogeographical and palaeogeographical problems raised by the recent discovery, particularly to the difficulty of finding satisfactory solutions without assuming the movement of land masses.

MINERALOGICAL SOCIETY.

Anniversary Meeting, 9th November, 1933.

The following were elected officers and members of Council:—

President, Sir Thomas H. Holland; Vice-Presidents, Sir William H. Bragg and Mr. Arthur Russell; Treasurer, Mr. F. N. Ashcroft; General Secretary, Mr. W. Campbell Smith; Foreign Secretary, Professor A. Hutchinson; Editor of the *Journal*, Dr. L. J. Spencer; Ordinary Members of Council, Professor C. E. Tilley, Professor P. G. H. Boswell, Professor H. L. Bowman, Dr. L. Hawkes, Dr. W. R. Jones, Dr. F. Coles Phillips, Mr. J. B. Scrivenor, Mr. F. A. Bannister, Mr. T. Crook, Dr. W. F. P. McLintock, Mr. L. R. Wager, Dr. A. K. Wells.

Professor P. L. Dravert (of Omsk): Shower of meteoric stones in the neighbourhood of the village of Kuznetzovo, West Siberia, on 26th May, 1932. Between 5 and 6 p.m. in a cloudless sky ten detonations were heard and one stone of 2 kg. was seen to fall, making a small oblique hole and then rebounding. Eight stones with a total weight of 23 kg. (the largest 16 kg.) were collected. Two of them, found 300 metres apart, can be fitted together on their flat crusted surfaces. The stone is a greyish-white friable chondrite with inclusions of troilite and grains of nickel-iron. The troilite was thought by the peasants to be gold, which led to the destruction of some of the material.

Mr. P. A. Clayton and Dr. L. J. Spencer: Silica-glass from the Libyan Desert. Clear, greenish-yellow silica-glass has been found in considerable amount as wind-worn masses up to 10 lb. in weight over an area of 80 by 25 km. at about 500 km. S.W. of Cairo, near the border of Italian Cyrenaica. It is found lying on the surface of the Nubian Sandstone in the " streets " between the north-south sand-dune ridges. Analysis by M. H. Hey shows SiO_2 97·58 per cent with small amounts of Al, Ti, Fe, Ca, Na, and a faint trace of nickel. Specific gravity 2·206, refractive index 1·4624 (sodium-light), hardness 6. Some pieces are cloudy, due to presence of minute (0·1 mm.) bubbles. Effective gem-stones have been cut from the material. It shows certain relations to tektites and also to the silica-glass from meteoric craters, but no craters have been recognized at the locality.

Dr. L. J. Spencer: Fictitious occurrences of iron silicide (ferrosilicon). Bright, steel-grey nodules of iron silicide (FeSi), very resistant to acids (except HF) and to weathering, are sometimes present in the calcium carbide residues from acetylene lamps. This waste material has been found at times in strange situations and has on two occasions been described as a new mineral. It has also been thought to be meteoric. Occurrences in the gold dredgings in British Guiana and in the diamond fields of South Africa are readily explained by the use there of acetylene flares.

Mr. Arthur Russell: Notes on the occurrence of wulfenite at Brandy Gill, Carrock Fell, Cumberland; and of leadhillite at Drumruck mine, Gatehouse of Fleet, Kirkcudbrightshire. Wulfenite occurs here in small (1·5 mm.) honey yellow platy to scale-like crystals, often nearly circular in outline. Thirteen specimens were collected from an old trial level dump. Leadhillite, a single specimen showing six-sided tabular crystals up to 5 mm. in diameter, was collected during the working of the Drumruck mine in 1917.

Mr. Arthur Russell : On the occurrence of harmotome at several new localities in the British Isles. The occurrence of harmotome at the following mines is described : Snailbeach mine, Minsterley, Shropshire ; Cwm Orog mine, Llangynog, Montgomeryshire ; Settlingstones mine and Stonycroft mine, Fourstones, Northumberland ; Whitespots mine, Newtonards, Co. Down, and Foxrock mine, Glendasan, Co. Wicklow.

Professor C. E. Tilley and Mr. A. R. Alderman : Progressive metasomatism in the flint nodules of the Scawt Hill contact zone. The flint nodules of the Chalk of the Scawt Hill contact zone provide striking examples of progressive metasomatism. Various stages—of which analyses are given—from an original nodule composed wholly of quartz to an assemblage built up essentially of wollastonite, melilite, and alkali-pyroxene can be traced. In the successive stages of replacement the characteristic shape and form of the nodules is preserved. The assemblages thus provide a particularly convincing illustration of a replacement process unaccompanied by volume change. The nature and source of the replacing solutions is discussed.

Dr. F. Coles Phillips : Some relationships between the reflectivities of sulphide ore-minerals. A review of the reflectivity data now available for a large number of opaque minerals has shown that the relative reflectivity of simple sulphides, selenides, and tellurides increases with atomic number. " Molecular refractivities " of over forty complex sulphides calculated from the measured reflectivities agree well with values computed from the " molecular refractivities " of the constituent simple sulphides, assuming additivity. This relation indicates a method of calculating the reflectivity of an ore-mineral and also affords a useful check on the specific gravity quoted in the literature. The " molecular refractivities " of sulphur, selenium, and tellurium calculated from reflectivities also agree with values derived from a study of transparent ionic compounds.

Dr. F. Coles Phillips : A critical list of the specific gravities of the sulphides and allied ore-minerals. Variations in the values of the specific gravities of ore-minerals quoted in the literature are due to misprints, determinations on impure material or mixtures, and actual variation in composition of specimens owing to solid solution. The probable correctness of a specific gravity determination can be checked by comparison of calculated and computed " molecular refractivities ", by direct specific gravity determination of the synthetic mineral, and by the X-ray method. These criteria govern the author's choice of critical values, when correlated physical and chemical data on the same specimen are lacking. They are tabulated together with the maximum range of variation recorded in the literature.

REVIEWS.

THE GEOLOGY OF BRITISH SOMALILAND. By W. A. MACFADYEN, Ph.D. pp. 1–87, 4 plates with map in folder. London: Crown Agent for the Colonies, 1933. Price 12*s.* 6*d.*

THIS memoir, published by the Government of the Somaliland Protectorate, is part i of the Geology and Palaeontology of British Somaliland. The descriptive palaeontology will form future parts. It includes a summary of previous work, a description of the physiography and drainage system, a very interesting section on the tectonic structure, and a short discussion of the lithology and fauna (with provisional determinations of some of the commoner fossils) of the geological formations, which include Archaean, Jurassic, Cretaceous, Eocene, Oligocene, Miocene, Pliocene to Recent (the Aden Volcanic Series), and Raised Beaches, Terraces and Alluvium. The author has been responsible for the mapping of most of the area, and is accordingly able to correlate the results of previous work, and to suggest definitive stratigraphical names for practically the whole of British Somaliland, in place of the somewhat muddled terminology which had grown up.

Appendices include notes on the igneous and metamorphic rocks (chiefly Archaean) by Dr. Harker; a note on the water supply, and a list of the fossil localities (defined, one is glad to see, by latitude and longitude) and details of 29 measured sections.

MINERALS AND THE MICROSCOPE. By H. G. SMITH. Third Edition, pp. xiii + 124, with 12 plates and Newton's Scale in colour as a frontispiece. London: Murby, 1933.

THE third edition of this useful little book contains eight more pages than the first edition: the concluding section on petrology has been entirely rewritten and expanded, whereas the rest has undergone slight compression.

The new section on petrology gives a useful summary, necessarily very condensed, of modern views on the origin and classification of igneous rocks. It may be felt that the new diagram of rock-classification on p. 103 could have been improved by rotating each square clockwise through 45°, or replacing the squares by diamond-shaped figures, which would show the true relations of the alkaline and calc-alkaline series more clearly.

A short but useful section is devoted to the minerals of the sedimentary rocks, with a list of the characteristics of the chief minerals of heavy residues. It is hardly correct to say that rutile is "very dark brown, almost opaque": it is often quite bright orange-yellow, while the brick-red colour in reflected light, even of yellow crystals, is highly characteristic. The appearance of mineral grains by reflected light is often a useful means of identification, but can really only be learnt by experience.

HISTORICAL GEOLOGY. By RAYMOND C. MOORE, Ph.D. pp. 1–659, 413 text-figures. McGraw Hill Publishing Co., Ltd. 24*s*.

WHILST no doubt primarily intended for American students, this book will undoubtedly be useful to advanced students in other countries who desire a general up-to-date account of American stratigraphy. The book is well planned, and the vertical sections and block diagrams good and clear, and hence most instructive. The idea of having reproductions of fossils in groups has much to recommend it, and whilst the author is no doubt wise in selecting for his illustrations figures from well-known authors, the reproductions of these are not good: they lack definition and as a result the characteristics for which a student naturally looks are not brought out. Apart from this, the book is certainly to be recommended. There is a useful bibliography of selected references.

G. L. E.

APPLIED GEOPHYSICS IN THE SEARCH FOR MINERALS. By A. S. EVE and D. A. KEYS. Second edition, pp. x + 296, with 112 figures. Cambridge University Press, 1933. Price 16*s*.

THE practical work of geophysical prospecting requires a mathematical and physical training beyond that possessed by most geologists, and it is wisely pointed out in this book that the best results are likely to be achieved by the co-operation of geophysicists, mining engineers, and geologists. The book is primarily intended for the first category, but will also be useful to the others by giving them an idea of the scope of the subject and the number of different methods now available. It is stated in the preface that the changes made in this new edition are not great, the character, size, and price being conserved.